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A study of the mortar making qualities of Illinois sand

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A STUDY OF THE MORTAR MAKING QUALITIES OF ILLINOIS SANDS

BY

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THESIS

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INTRODUCTION.

This thesis embodies the results of a series of tests made to determine the mortar making qualities of the sands usually employed in a number of the most important cities of Illinois.

The subject matter is divided into two parts:- Part 1, General Discussion, and Part 2, Tests of Illinois Sands. Part 1 presents a general discussion of the characteristics of sand, the effect of these characteristics on mortar, the methods of testing sand, and the interpretation of the results of tests. Part 2 describes the testing of thirty-two samples of sand used in important cities of Illinois. The details of the methods employed in collecting and testing the samples are first given. A short description of each sand is next given followed by the conclusions drawn from the results of the tests. The numerical results of the tests follow in the form of tables and the whole concluded with a set of plates showing graphically the results of the sieve analysis.

The series of experiments herein described extended over a period of about four years. Many tests were made by five members of the senior civil engineering classes in connection with bachelor's theses prepared under the direction of the writer. Credit is due Mr. J. W. McManus,'07, Mr. E. B. Adams,'08, Mr. F. T. Heyle,'09, and Messrs. G. A. Barth and W. Koestner,'10 for the data thus obtained. The writer has personally duplicated substantially all of the tests made by the students, and in addition has made a considerable number of other tests.

The writer desires to express his appreciation of the generosity of the various city engineers of the state in sending samples of sands for these tests. The writer is also indebted to Mr. B. L. Bowling, Assistant in charge of the Cement Laboratory at the University of Illinois, for his assistance in making certain tests and in supervising the work of the students in the laboratory.

PART 1.

GENERAL DISCUSSION.

Mortar. Mortar is the material used in filling the joints of masonry. Its purpose is threefold:-first, to form a solid bed or resting place for the blocks of stone or other material; second, to bind these blocks together; and, third, to prevent the entry of water, etc. In heavy stonework, the first and last of these requirements are of the greater importance, since the weight of the blocks is sufficient to hold them in place and they therefore do not need to be bound together by the mortar. In light stonework or brickwork the second requirement becomes more important, since the blocks are deficient in weight. In concrete work, however, this second requirement becomes of the greatest importance since the strength and therefore the value of the concrete depends on the cementing or binding together of fragments of rock.

Modern mortar consists of some cementing material mixed with some inert aggregate. The purpose of the aggregate is to increase the volume of the mortar with some material costing less than the cementing material and hence to decrease the total cost of the mortar used. The aggregate is usually natural sand or "crushed stone screenings". The cementing material used in mortar for ordinary brickwork is usually lime but in important brick work and in concrete it is always cement. Since the aggregate normally forms from one half to four-fifths of the mortar, its characteristics exert a marked influence on the characteristics of the mortar. The prin-

cipal requirements of a mortar are strength, both cohesive and adhesive, and durability and its value is gaged by these properties.

The durability of a mortar depends on the durability of the materials composing it. A good cement is quite durable under ordinary condition, and on important work is always tested to make sure that it is not deficient in this respect. The durability of the sand depends on its composition. To be durable it must be composed of such minerals as are durable and not acted on by water, frost, gases, etc.

The strength of a mortar is dependent on the strength of the materials and on the adhesion between the cement and the sand, hence the strongest mortar is composed of Portland cement and hard, rough, irregular-grained sand. Mortar is most frequently used where it is subject to compression but in testing the mortar it is much more frequent to suject it to tension. This is due to the fact that tensile tests are more easily made than compressive tests and hence yield more uniform and comparable results. There is, however, no apparent relation between the tensile and compressive strengths of mortar, probably on account of the "sharpness" of the sand (see "Sharpness" p. 6.) but mortars which possess high tensile strength also have high compressive strength and hence tensile tests serve to compare the strengths of different mortars.

Two general laws, frequently called "laws of proportioning", govern the strength of cement mortars. These laws are:-

"1. For the same cement and the same sand, the strength increases with the amount of cement in a unit volume of the mortar.

2. For the same proportion of cement in a given volume of of mortar, the strongest mortar is that which has the greatest

density, i.e., contains the largest proportion of solid matter."

(See Baker's Masonry Construction, 10th. Ed. p.110.)

The first of these laws is the one in common use and is quite well understood. It must be remembered, however, that the strength does not increase directly with the increase in the amount of cement, and that the limit is approximately that of the neat cement. The second law is less well known but is of great value in determining the best proportion of cement to use with any particular sand.

Sand. Sand is rock-meal formed either naturally or artificially by the grinding or crushing of natural rocks. If this grinding is done by nature the product is known as "natural sand" or more frequently, simply as "sand". If the product is the result of artificial crushing, it is known as "crushed rock", and since only the finer particles are used as sand, these must be screened out and hence this material is usually known as "screenings", the kind of rock used being given in connection with this term.

The characteristics of the sand which affect the character of the mortar are its composition, sharpness, cleanness, fineness, and percentage of voids.

Composition. Natural sands, being formed by the processes of nature, possess quite a diversity of materials in their composition. Some of these minerals are hard, durable, and of considerable strength, others are soft, friable, and subject to decomposition. Sands which are old, geologically, such as ocean or lake sands, generally contain a large amount of silica (quartz) which is both hard and durable. The other materials present are also likely to be strong and durable since the soft and decomposable materials would most likely be destroyed in the process of making

the sand. Glacial sands on the other hand quite frequently contain considerable quantities of detrimental materials. The sands used in Illinois are almost all of glacial origin and as such show quite variable composition but on the average they contain little or no materials whcih are not durable.

Crushed stone screeings show no more variation in composition than is found in the particular rocks of which they are made.

Sharpness. Sands with grains of irregular shape are called "sharp". This term, however, is purely relative as no natural sand possesses grains which are actually sharp.

Sharp sands are preferable to rounded sands, particularly under compressive loads, since the irregular shaped grains will interlock and set up considerable "internal friction" or resistance to the movement of the grains, and therefore there is less tendency for the sand or mortar to squeeze out. This internal resistance of the sand has little or no effect on the tensile strength, sands differing only in sharpness showing practically the same tensile strength. These facts probably account for there being no fixed relation between the tensile and compressive strengths of mortars.

Another argument often given in favor of sharp sands is that they aro rougher and therefore the cement adheres better and gives a stronger mortar. A close examination of the sands seems to indicate that the opposite is really the true condition. Sharp sands are always those of more recent formation and hence are those in which the rocks composing it have been recently broken to pieces. The fractured surfaces of these pieces, particulary when of the harder rocks, are most generally very smooth and often quite glassy. On the other hand the rounded grains are those which are older and

the grains have been rounded by the constant grinding against each other. In this grinding the smooth surfaces are roughened, just as the gloss on a polished surface is removed by sand-paper. This condition is particularly true of sands containing a large proportion of quartz.

It is also sometimes claimed that sharp sands contain a larger percentage of voids than rounded sands and therefore require more cement, but again the reverse seems to be the true state of affairs. The statement is evidently based on determinations of the voids in sands which have been compacted by ramming. This method of compacting does not allow the sharp grains to shift to any great extent and therefore the smaller ones do not entirely find their way into the spaces between the larger, in this way producing a considerable percentage of voids. If the sharp sand is compacted in such a way as to allow the grains to shift the smaller grains find the vacant spaces, resulting in a decrease in the voids. Sands with rounded grains will compact about the same either way. Sample No. 21 (see page 39.), the sharpest of the natural sands shows the lowest percentage of voids (30.1) although it is not as well graded in sizes as some of the other sands. Likewise the limestone screenings (Sample No. 4.) which are actually "sharp" shows a very low percentage of voids (28.5) when compacted by jarring, considerably less than the same sample does when compacted by ramming.

The sharpness of a sand is often tested by rubbing a small quantity between the fingers and noting the sound produced. This test is absolutely worthless so far as sharpness is concerned. The sound produced is dependent only on the composition, fineness, and cleanness of the sand. Two sands, differing only in sharpness will

produce sounds exactly alike when so tested. (Sample No. 21, the sharpest, and the Ottawa Standard Sand, the roundest, are scarcely distinguishable when tested in this way.) If the sand is dirty, particularly if the grains are coated, the sound produced is quite dull, irrespective of the degree of sharpness.

The only sure way to determine the sharpness is to examine the sand carefully with a magnifier.

Cleanness. The cleanness of the sand has a very marked effect on the strength of the mortar. A very thin coating of clay, loam, or organic matter on the sand grains will prevent the adhesion of the cement and greatly weaken the mortar. If, however, the foreign material is loose, or is removed from the grains in mixing, it will have no deleterious effect, unless present in very large quantities, and in some instances may prove to be a positive benefit. If the sand is quite deficient in fine material, or the mortar is very lean, the addition of finely divided clay may aid in filling the voids and thus make the mortar stronger by binding more of the sand grains together, although the cement itself is doubtless weakened by this admixture. This, in other words, simply amounts to using a larger proportion of a somewhat weaker cement.

Since clay, loam, etc., will remain suspended in water for a considerable time, when finely divided, it is often termed "suspended matter" and is so designated in the following pages. Sticks, leaves, straw and the like should never be allowed in sand and are not included under the ordinary term of "cleanness".

The cleanness of a sand may be judged by squeezing a handful of the moist sand. If clean, it will fall apart on opening the hand,

if very dirty, it will remain sticking together. A better way is to rub a small quantity of the dry sand on a sheet of white paper. A clean sand will leave no stain, whereas a dirty sand will discolor the paper to an extent depending on the amount and character of the suspended matter.

"The cleanness of a sand may be tested quantitatively by agitating a quantity of the sand with water in a graduated flask; after allowing the mixture to settle the amount of precipitate and of sand may be read from the graduation. Care should be taken that the precipitate has fully settled, since it will condense considerably after its upper surface is clearly marked." (Baker's Masonry Construction, 10th. Ed., p.87.) This method at best is only approximate and is open to considerable error. Unless the quantity of water is large, compared with the sand, a considerable proportion of the suspended matter will be held by the water in the voids of the sand and hence is not apparent on the graduation. This tends to give values which are too low. On the other hand, it is difficult to determine the dividing line between the sand and the precipitate, particularly if there is a large amount of very fine sand. This may produce results which are either too large or too small, but it is more likely that the fine sand will be included in the reading of the precipitate which would give results which are too large. In addition, the suspended matter being more or less flocculent never compacts as much as the sand and therefore the amount read from the graduation is again too large. With sands which contain a large amount of clay adhering to the grains it is not all removed by the single agitation and the results then are entirely too small. In general the results obtained by this method

are too large but this is on the safe side if they are to be used as a basis for the acceptance or rejection of the sand.

The above method may be improved by weighing the sand before testing, then after agitating it with water allow a short time for the sand to settle and then decant the dirty water. This washing being continued until the water is not discolored, the sand redried, the loss of weight will give quite accurately the amount of suspended matter. Of course this method would require more time but the increase is not considerable when the accuracy of the determination is taken into consideration.

For the details of this method as employed by the writer in the tests of Illinois sands see page 24.

The material removed in this way is extremely fine, and if it could be separated by sifting would pass the very finest sieve. Mr. B. L. Bowling, Assistant in charge of the Cement Laboratory at the University of Illinois, found that with a fair average sand containing about 1.5% of suspended matter, almost exactly the same amounts passed the No. 200, 150, and 100 sieves, whether the suspended matter had been removed before sifting or not. This indicates that the greater part of the suspended matter normally remains distributed throughout the sand, adhering as dust to the grains, and is therefore not separated by sifting. For this reason the test for cleanness should always be made before the sieve analysis (see page 14.)and the washed sand used in the latter test, and the amount of suspended matter added to the amount of material passing the finest sieve.

The amount of suspended matter in natural sands is quite variable. River and lake sands are usually the cleanest, rarely

containing more than about 1.0% of suspended matter. Bank sands frequently contain 3.0 to 4.0%, and much larger quantities than these are not uncommon. The cleanest bank sand tested by the writer contained but 0.2% of material in suspension and the dirtiest contained 18.3%.

The amount of suspended matter in a sand is also quite deceptive, and often misleads an engineer in his opinion as to the fitness of the sand. If the suspended matter, even in small quantities, is free the dry sand will appear quite dusty and will "smoke" in handling, often resulting in the sand being undeservedly rejected as "too dirty". At the same time a very dirty sand may be accepted because the dirt adheres to the grains and is not so evident in the handling. These conditions are well illustrated by the sands from Bloomington and Joliet. (Samples No. 7 and 18.) The former was reported by the city engineer as "too dirty for concrete". It contained 8.0% of suspended matter but showed a considerably higher tensile strength than several of the cleanest river sands which the same engineer would probably have used without question. The latter was reported by the city engineer as "being used in all kinds of work". It contained 18.3% of suspended matter and the tensile tests showed it to be almost the weakest sand tested.

Sands are sometimes washed to remove the dirt. Any method of washing which is likely to be used in cleaning sands in commercial quantities will usually remove a large part of the fine sand with the dirt. If the amount of fine material is small this may result in a weakening of the mortar made from the sand. If the sand is very dirty, or the grains thoroughly coated with clay, the washing may greatly improve the mortar. In the case of the sand

from Joliet, mentioned above, the tensile strength at twenty-eight days was increased about 35% by a thorough washing.

Voids. The second law of proportioning (see page 4.) states that for the same proportion of cement, the sand giving the lowest percentage of voids yields the strongest mortar, or, in other words, the sand with the lowest percentage of voids will give the strongest mortar with the least cement.

The percentage of voids in a sand depends on the amount of compacting of the sand and on the gradation of the sizes of the sand grains. Experience has shown that the amount of compacting varies with the method of compacting employed and therefore in determining the voids in different sands some method of compacting should be adopted which will compact all alike and thus secure comparable results. Whenever the results of the determination of the voids in sand is given, the method of compacting the sand and of making the determination should also be given.

There are two general methods of determining the percentage of voids in sand, which for convenience may be called the "direct measurement method" and the"specific gravity method".

The direct measurement method consists in filling a vessel of known capacity with sand and water, both being brought to the same level. Since the water just fills the voids, if the volume of sand used and of the water used are known the percentage of voids is easily computed.

The vessel my be filled with dry, compacted sand and the water poured into it until the water just comes to the surface and the amount of sand and of water used determined. This method is subject to considerable error, due to the air which normally fills

the voids not entirely escaping and thus preventing the water from entirely filling them. Results obtained in this way are always too small and not uniform.

The vessel may be filled by adding the sand and water in small increments and compacting the sand by shaking, both the sand and water being kept at about the same level and finally brought to the same level when the capacity of the vessel is reached. The results obtained by this method are also unreliable, due to irregularity in compacting the sand and to the "swelling" of the sand due to capillarity and surface tension. The results are particularly poor with very fine sands.

The specific gravity method is, on the whole, much the most satisfactory. The specific gravity of the sand is first determined independently, a Schuman Specific Gravity Flask being quite convenient for the purpose although not essential. A vessel of known capacity is then filled with dry sand, compacted by some method to secure uniform results, and the weight of the sand used determined. The data to be used is therefore the specific gravity of the sand and the weight of a given volume of the sand. If now the given volume is multiplied by the specific gravity of the sand the product is the weight of an equal volume of solid sand, i.e., sand containing no voids. Denote this value by S. The difference between this weight (S) and the actual weight of the given volume of the sand (W) is the weight of a mass of solid sand equal in volume to the voids in the actual sand, hence the ratio of voids to the total volume is equal to $\frac{S - W}{S}$. Since the amount of voids is usually expressed in percents of the total volume, the percentage of voids is $100 \cdot \frac{S - W}{S}$

The uniformity of the results obtained by this method depends

on the care taken to secure uniformity in the compacting of the sand. For the details of the method used by the writer see page 27.

Fineness. The fineness of the sand bears an important relation to the strength of the mortar. Coarse sand is usually preferable to fine since there is less surface to be covered by the cement, and hence less cement is required. The fine sand and the coarse sand may, however, contain the same percentage of voids and for that reason require the same amount of cement, but even in that case the coarse sand will ordinarily yield the stronger mortar. A sand in which there is the proper gradation of sizes of grains will contain the lowest percentage of voids and in accordance with the second law of proportioning will require the least cement to form the strongest mortar.

The sizes of the grains in natural sands varies from microscopic to the largest bowlders. The coarse material is termed "gravel" and the fine material "sand" but the dividing line between sand and gravel is purely arbitrary. The maximum size of grains to be considered as sand is taken by different authorities from 1/8 to 3/8 inches. Several American writers have adopted 0.2 in. as the maximum size of sand grains, and the writer has also adopted this size (0.2 in.) as the size to be used. The size of particles of crushed stone is limited by the size which can pass the crusher, but in comparing the screenings with natural sands the same maximum size should be used for both materials.

The fineness of a sand is determined by passing it through a series of sieves having meshes of different sizes and determining the percentage of the whole passing each sieve. The sieves used for this purpose are made of standard wire cloth having from five

to two hundred meshes per linear inch. There does not seem to be a great deal of uniformity in the sizes chosen by different observers but it would be of a great deal of advantage in making comparisons if all used the same. After a careful study of the sieve analyses made at the University of Illinois and at the U. S. Testing Laboratory at St. Louis the writer recommends the following set as the most satisfactory for laboratory use:- Standard meshes No. 5, 8, 16, 30, 60, 100, 200, and the pan. The use of but these seven sieves materially reduces the labor of making the test and the results are as satisfactory as when a larger number of sieves are used. For field use a set composed of Nos. 100, 30, 16, and pan will be very convenient and satisfactory.

Sieve analysis curves are graphical representations of the results of the sifting. They are usually platted with diameter of grains as abscissas and percents passing (smaller than given diameter) as ordinates. This method of platting gives a continuously ascending curve. Sometimes the curves are platted with the percentage retained between each pair of sieves as ordinates but curves of this kind are saw-toothed and difficult of interpretation and comparison.

Taylor and Thompson in their book entitled "Concrete, Plain and Reinforced", state that a material for which the sieve analysis curves approaches a parabola has the least voids. For convenience this will be referred to as "parabolic grading". In Bulletin No. 331 of the U. S. Geological survey comparisons were made with a line of "uniform grading". Some tests by the writer seemed to indicate that since the material passing the No.100 sieve (including the suspended matter) is practically as fine as the cement, it

should not be included with the sand and therefore the parabola should cross the axis of abscissas at the ordinate for the No.100 sieve. (Further tests did not confirm this) This will be referred to as "modified parabolic grading".

In order to make a comparison of these different gradings the writer prepared, artificially, a sample of sand graded in accordance with each, using material screened from a good building sand. On determining the voids it was found that the parabolic grading gave 21.1%, the uniform grading 30.6% and the modified parabolic grading 30.4%. It will be noted that there is little difference in the amount of voids between the modified parabolic and the uniform gradings, but that the parabolic grading with 17% of material passing the No. 100 sieve reduced the voids almost one-third. Each of these sands was then mixed with cement in the proportion of 1:3 by weight and the voids redetermined. The parabolic grading gave 22.9%, the modified parabolic, 22.0% and the uniform, 21.6%. Note that the uniformly graded sand, which contained the most voids, gave the least when mixed with the cement. Briquettes of these mixtures were broken at the age of seven days. The tensile strengths of the parabolic, modified parabolic and uniform gradings were, 192, 257, and 277 lb., respectively. It will be noted that these results are in accordance with the second law of proportioning.

Fuller further discovered that there should be an excess of fine material over that indicated by the parabola, when the cement was included in the material, to secure to densest and strongest mortar. Both the modified parabolic grading and the uniform grading show such an excess when mixed with the cement and the difference of their strengths is not considerable (20lb.)

The tensile strength of the parabolic graded sand is quite low, comparatively, and is probably due to too great an excess of fine material. The parabola calls for 17% to pass the No.100 sieve, and since 25% of the mixture was cement, the cement was mixed with about 50% of its own weight of material as fine as itself, which resulted in a weakening of the cement paste binding the sand grains together.

Plate 33 shows the sieve analysis curves of these artificial sands and also of the 1:3 mixtures with cement.

It has been quite definitely determined (the above experiments show the same) that the cement should be included in making the tests for voids to secure the maximum density and strength. This is simply another way of saying that the second law of proportioning should not be interpreted to mean that the sand with the lowest percentage of voids will give the greatest strength when mixed with a given amount of cement; but that the sand which, when mixed with a given amount of cement, gives the lowest percentage of voids will give the strongest mortar.

Natural sands are usually deficient both in very fine material and in coarse grains, the excess usually being between the No. 40 and No. 60 sieves. Natural sands therefore show a high percentage of voids as compared with a sand of parabolic grading but when mixed with cement give very dense mortars.

Increase of Strength. The rate of increase in the tensile strength with age is quite variable, depending on the fineness of the sand, the hardness of the grains and the amount and distribution of the suspended matter. Dirty sands, as a rule, reach almost their maximum strength at an early age. This is on account of the adhesion of the cement to the sand grains is less than the strength

of the cement, and the increase of strength after the maximum adhesive strength is reached is due to the increase of strength in the cement itself. Clean, rough sands develop their maximum strength more slowly, since the maximum adhesive strength is not reached until the cement has attained almost its full strength. For these reasons 7-day tests are of little value for comparison of different sands and those made at 28-days are not as reliable as those of 90-days. Tests made at 28-days are sufficently comparable for commercial work, however.

Weight of Sand. The weight of sand depends on the specific gravity, the percentage of voids, the compactness, and the contained moisture. The weight is easily computed from the data taken in determining the percentage of voids.

Dry sands, well compacted by jarring, weigh from 100 to 116 pounds per cubic foot. An average sand weighs about 112 lb. If the sands are loose instead of compacted the weight is about 20% less.

SPECIFICATIONS

General

Definition. The term "sand" shall be understood to mean natural sand which has been screened to pass a sieve having square openings of 0.2 of an inch.

Composition. The sand shall be composed of rock materials which are hard, tough, and durable. Quartz sands are the best but limestone, granite, flint and chert are not objectionable, providing they do not aggregate more than 50% of the whole. Ocherous rocks, feldspar, shale and similar rocks which are soft or are likely to decompose are objectionable if present in more than very small quantities.

Sharpness. Sands with grains of irregular shape are preferable to those with rounded grains, but this shall not be a basis for the rejection of a sand fulfilling these specifications in all other respects.

Cleanness. The sand must be free from lumps of clay, loam, or other foreign material, and the grains must not be coated with such material to such an extent that it is not easily removed by wetting.

No sticks, shavings, chips, paper, straw, grass, leaves, or similar material are allowable under any conditions.

No. 1. Sand.

Sand to be used in first class masonry of all kinds, requiring maximum strength, and in reinforced concrete, shall be known as "No.1. Sand", and in addition to the above specifications shall conform to the following:-

Cleanness. No. 1. Sand shall not contain more than 4.0% by weight of suspended matter composed of finely divided clay or loam, when tested as follows:- A weighed sample of the sand of not less than two pounds shall be thoroughly agitated with water in a vessel about ten inches deep and holding about one gallon. After allowing at least one minute for the sand to settle the dirty water shall be siphoned off with a tube not more than 3/8" in internal diameter, care being taken that the sand is not disturbed or the water drawn down to within less than one inch of the surface. This washing process shall be continued until the water shows no discoloration. The sand shall then be removed and as much water drained from it as possible. After drying for at least 24 hours at a temperature of about 200° F. or by exposure in a thin layer for at least 48 hours to dry, warm air, it shall be reweighed. The loss of weight shall be considered as the amount of suspended matter and the percentage of the whole sample computed.

Fineness. The sand shall be well graded in sizes of grains. Not less than 20% nor more than 60% by weight shall pass the No.16 sieve and not less than 3% nor more than 8%, including the suspended matter, shall pass the No.100 sieve.

Voids. The voids in the dry sand, when well shaken, shall not exceed 31.0% of the total volume.

Tensile Strength. Briquettes of mortar in the proportion of 1:3 by weight, when tested at 28 days shall develop not less than 35% of the tensile strength of the neat cement at the same age.

No. 2. Sand.

Sand for use in monolithic concrete, concrete sidewalks, ordinary masonry and similar work not requiring maximum strength

shall be known as "No. 2. Sand". It shall fulfill the above specifications except as follows:-

Cleanness. The amount of suspended matter shall not exceed 8.0%.

Fineness. Not less than 20% nor more than 80% by weight shall pass the No.16 sieve and not less than 3% nor more than 20%, including the suspended matter shall pass the No.100 sieve.

Voids. The voids shall not exceed 33.0% of the volume.

Tensile Strength. The tensile strength of 1:3 mortar at 28 days shall not be less than 25% of that of the neat cement.

Plastering Sand.

Sand for interior plastering shall conform to the specifications for No. 2. Sand.

The sand for the finishing coat, however, shall be of the requisite fineness to give the desired finish.

Sand for Pavement Filler.

Sand to be used in making grout filler for brick pavements shall conform to the above specifications for No. 2. Sand, except as follows:-

Fineness. All (100%) shall pass the No.16 sieve.

Voids. The voids shall not constitute more than 37.0% of the volume.

Tensile Strength. The tensile strength of 1:3 mortar at 28 days shall not be less than 20.0% of that of the neat cement.

PART 2.

TESTS OF ILLINOIS SANDS.

Collection of Samples. Nearly all of the samples of sand used in these tests were donated for the purpose by various cities of the state, through the courtesy of their respective city engineers. A few of the samples were collected personally by students of the University of Illinois in connection with the preparation of their bachelor's theses.

The following list gives the names of the cities contributin samples together with the "Sample Numbers" of the sands contributed by each.

Aurora..........17.	Galesburg.........13.
Beardstown......27.	Jacksonville......26.
Bloomington......7.	Joliet............18.
Cairo...........25.	Moline............19.
Champaign.......12.	Mt. Carmel........28.
Chicago....1,2,3,4.	Paris.............23.
Decatur.........14.	Rockford...........8.
E. St. Louis....21.	Springfield..9,10,11.
Elgin..........5,6.	Taylorville.......24.
Freeport.....15,16.	Waukegan..........22.

Samples No.20, 29, 30, 31, and 32 were collected by students.

These samples were shipped to the laboratory for the most part in double duck or grain bags, some few of the coarser ones in single bags, and a few in boxes.

As soon as a sample was received it was given a "Sample

Number" by which to identify it in the tests. These Sample Numbers and the names of the various sands are given in all of the tables. It will be noted that the name is not always that of the city donating the sample but is the name of the place near which the deposit is located.

The sands were first screened through a sieve having openings of 0.2 in. They werethen placed on a steam heated drier and allowed to dry for at least twenty-four hours after which they were stored in wooden lockers in a room maintained at about 70 °F. until wanted for testing.

Tensile Strength. The cement used in making the tensile tests was the "Chicago AA, Portland". This particular brand was chosen entirely on account of the ease of obtaining it on the local market. Each bag of it was tested before using and as a result of these tests it was found that the different bags, although bought at several different times, were quite uniform in quality. The average amount passing the No.100 sieve was 95% and passing the No.200 sieve 80%. The average amount of water required for normal consistancy was 21%. The tensile strength of the neat cement is given in Table 1, p.49 .

The mortar used was in the proportion of 1:3 by weight in every case and was mixed with 9% of water, corresponding to the 21% required by the neat cement. This amount of water was ample for use with the hard grained, clean sands but with the softer and dirtier sands the resulting mortar was often quite dry. It is not believed, however, that this has any appreciable effect on the tests, particularly those at twenty-eight and ninety days.

The mortar was mixed in batches of 1000 grams (250 grams of

cement and 750 grams of sand) and six standard briquettes molded from each batch. Three batches (18 briquettes) were made from each sand and two briquettes from each batch (6 in all) were broken at each of the three ages of 7, 28, and 90 days.

After molding, the briquettes were stored in moist air for about twenty-four hours when they were removed from the molds and stored in flowing water maintained at about 70° F. On reaching the proper age they were removed from the water and at once broken in a "Riehle Automatic Cement Testing Machine" applying the load at the rate of 600 lb. per minute.

The results of these tests are given in Table 1, pp. 49 - 51.

Cleanness. The sand was tested for suspended matter as follows:-

1000 grams of the dried sand was placed in a vessel of about one gallon capacity and thoroughly agitated with water. The mixture was then allowed to settle for about one minute, experience showing that this ordinarily allowed sufficient time for the sand to settle. The dirty water was then siphoned off with a ¼" rubber tube, care being taken to keep the end of the tube just below the surface of the water and also not to draw the water off to within less than one inch of the sand. The vessel was then refilled with clean water and the process repeated until the water showed no discoloration. The water was then carefully siphoned off and the sand transferred to a small pan. As much of the water as possible was then removed by jarring the sand until the water flushed to the top when it was removed with a pipette. The pan was then placed on the steam coil and the sand allowed to dry for at least twenty-four hours. It was then reweighed and the

difference between this new weight and the original 1000 grams, which was the amount of suspended matter removed, determined. The washed sand was then used in making the sieve analysis.

The time required to perform this washing operation varied from about fifteen minutes for the cleanest sands to about 2½ hours for the dirtiest, the average time being about one hour. With the dirty sand it was usually found necessary to "scrub" the sand between the hands to break and entirely removed the coating of clay from the grains.

The results of these tests are given in Table 2, p. 52.

Sieve Analysis. The nest of sieves used in the sieve analysis consisted of the following numbers:- 5, 8, 10, 16, 20, 30, 40, 60, 74, 100, 150, 200, and the pan. In a number of the earlier tests the numbers 5, 10, 150, and 200 were omitted.

The sand having previously been washed to remove the suspended matter as explained above was placed on the top sieve of the nest and the whole shaken for forty minutes on a "Per Se Testing Sieve Agitator" driven by power at 100 r.p.m. Experience showed that forty minutes was sufficient to properly sift a sample of about 1000 grams except in the cases of the very finest sands and with these samples of but 500 grams were used. It was also desirable to use but 500 grams of the fine sands in order to protect the fine sieves from injury by a large mass of sand being retained on them. The sand on each sieve was then carefully weighed and from these weights the amount passing and thence the percent passing each sieve was calculated.

The results of these tests are given in Table 2, p. 52. Plates 1 to 32 inclusive show the "Sieve Analysis Curves" of the

various sands. These curves are plotted from the data given in Table 2.

Specific Gravity. The specific gravity was determined by means of a Schuman Specific Gravity Flask. This flask consists of a bulb or bottle into the neck of which there fits, with a ground joint, a long graduated glass stem. The bulb was first filled with water and the stem inserted. More water was then admitted through a long stemmed funnel until it was above the zero of the graduations. The funnel was then carefully removed so as not to wet the inside of the graduated stem. Fifty grams of sand, carefully weighed, was then intoduced into the bulb in a fine stream so as to permit the air to escape and also not to stop up the tube. After allowing a minute or two for the water to clear, at the same time rocking the apparatus so that any air carried in by the sand might escape, the height of the water in the stem was again read. The difference between the two readings gave the volume of water displaced by 50 grams of sand, and since a cubic centimeter of water weighed practically one gram this also gave the weight of the water displaced. Another fifty grams of the same sand was immediately introduced in the same way thus giving two determinations of the displacement of 50 grams of sand, the sum of which should check with the difference between the initial and final readings which gave the displacement of 100 grams.

Since the specific gravity of a body is equal to its weight divided by the weight of an equal volume of water the specific gravity of the sands was easily determined from data taken as above. The specific gravities of the various sands are given in Table 3, p. 53.

Voids. Preparatory to determining the voids in the sands the writer made a number of experiments from which the following conclusions were drawn. First, that the amount of voids varies with the compactness of the sand; second, that the compactness of the sand varies with the method of compacting; third, that uniform results for the same sand can be obtained only by employing uniform methods and that for different sands some method affected but little by the fineness or sharpness of the sand; fourth, that the specific gravity method is the most reliable.

Some method of procedure was therefore desired which would compact all sands to the same extent, would be easy to perform, and could make use of a limited quantity of sand. After a number of trials the method described below was adopted as the most satisfactory.

The vessel used was a 500 c.c. graduated cylinder. The weight of the cylinder was first determined. About 20c.c. of dry sand was then poured into it and compacted by jarring. This jarring was accomplished by pounding the cylinder on a pad composed of eight thicknesses of heavy cotton flannel, giving twelve blows with a drop of about one inch, and taking care that the cylinder struck squarely and not too hard so that the sand was not "bounced" or thrown from side to side. Successive increments of sands were added in this manner until the cylinder was filled. It was then weighed and the difference between this weight and the weight of the cylinder gave the weight of the 500c.c. of sand. Then knowing the specific gravity of the sand the percentage of voids was computed as explained on page 13. The weight per cu. ft. was easily computed from the weight per 500c.c.

The weight of 500c.c. obtained by this method were remarkably uniform, not only when performed by the same person, but when different persons made observations on the same sand. The maximum variation from the mean of five determinations made by the same observer was but 7½ grams or about 0.8% . The maximum variation between the results of different observers on the same sand was about 1.5%.

Composition and Sharpness. The sands were all carefully examined under a magnifier having a power of about four diameters to determine the approximate composition and the relative sharpness. At the same time the distribution and character of the contained clay or other suspended matter was noted.

Photographs. Each sand was photographed full size, care being taken to secure a representative surface for photographing. These pictures (Figs. 0 to 32 inclusive) show the general appearance of the sands quite well.

DESCRIPTION OF SANDS.

Sample No. 0. (Fig. 0.) This sand is known as the "Ottawa Standard Sand, 20-30." It comes from the St. Peter formation near Ottawa and is screened to pass the No. 20 sieve and to be retained on the No. 30. This sand is composed of almost pure quartz and contains practically no suspended matter. The grains are almost globular in shape and nearly transparent. The specific gravity is 2.66, the weight per cu. ft. 108.7 lb., and the percentage of voids 34.6 .

FIG. 0.

Sample No. 1. (Fig. 1.) This sand is furnished by the Knickerbocker Ice Co., Chicago and although reported as a bank sand it is evidently a sand from along the shore of Lake Michigan. It is yellowish in color and is composed almost entirely of quartz. A large proportion of the grains are fairly angular with rather sharp edges. As shown by the sieve analysis (see Plate 1.) this sand is very fine, 99.8% passing the No.16 sieve and 69.5% the No.60 sieve. There is only 0.3% of suspended matter. The specific gravity is 2.655, the weight per cu. ft. 105.8 lb., and the percentage of voids 36.2 .

FIG. 1.

Sample No. 2. (Fig. 2.) This is a bank sand also of lake origin furnished by the Zander-Reum Co., Plasterers, Chicago. It is light gray in color and is composed principally of quartz with a small proportion of granite, flint, and limestone. The sieve

analysis (see Plate 2) shows this sand to be slightly coarser and somewhat better graded than Sample No. 1., 94.7% passing the No.16 sieve and 25.9% the No.60. It contains but 0.3% of suspended matter. The specific gravity is 2.655, the weight per cu. ft. 108.0 lb. and the percentage of voids 34.4 .

FIG. 2.

<u>Sample No. 3.</u> (Fig. 3.) This is another lake sand furnished by the Knickerbocker Ice Co., Chicago. It is light gray in color. The smaller grains are principally quartz while the larger are almost entirely granite, flint, limestone and chert. The sieve analysis (see Plate 3) shows this sand to be better graded than either of the preceeding samples. The suspended matter amounts to 0.3%. The percentage of voids is rather low for a sand showing a sieve analysis curve of this character being but 31.6 . The specific gravity is 2.695 and the weight per cu. ft. 115.1 lb.

FIG. 3.

<u>Sample No. 4.</u> (Fig. 4.) This is a sample of Joliet limestone screenings and was being used in Chicago. The stone is very close and even grained and possesses a very light blue tint. In crushing some of it passes into very fine dust but since the stone used was quite clean no test for suspended

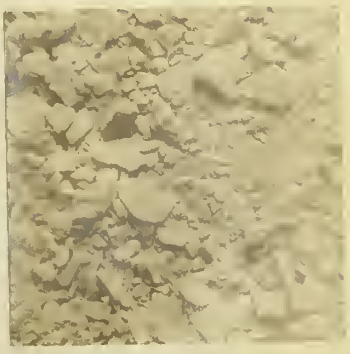


FIG. 4.

matter was made. An examination of the sieve analysis curve (Plate 4.) shows that this sample is almost uniformly graded and by comparing this curve with the others it will be seen that it is the only one which even approximates this grading. This sample also shows the lowest percentage of voids. The specific gravity is 2.75, the weight per cu. ft. 122.8 lb., and the percentage of voids 28.5.

Sample No. 5. (Fig. 5.) This sample of sand is from the Hammond Pit of the Chicago Gravel Co., near Elgin. It is yellowish gray in color and contains less quartz than an average sand. The other materials being principally limestone, flint, and chert. This is one of the coarsest sands tested, 55.0 passing the No.16 sieve and 7.4% the No.60. The

FIG. 5.

sieve analysis curve as shown by Plate 5 lies closest to the parabolic curve with the single exception of that of Sample No.14. (see Plate 14) This sand was reported as a "washed" sand but it contains 1.0% of suspended matter, a trifle more than Sample No.6 which is a "screened" sand from the same locality. The specific gravity is 2.72, the weight per cu. ft. 115.7 lb. and the percentage of voids 31.9 .

Sample No. 6. (Fig. 6.) This is a screened sand from the Stimpson Pit near Elgin. It is grayish yellow in color and contains a small proportion of flint, granite and chert. It is a little exceptional in that the fine grains are the more angular

FIG. 6.

the larger grains being well rounded. The sievo analysis (see Plate 6.) shows this sand to be somewhat finer than Sample No. 5. The specific gravity is 2.68, the weight per cu. ft. 114.4 lb. and the voids 31.6%.

<u>Sample No. 7</u>. (Fig. 7.) This is a bank sand obtained along Sugar Creek, near Bloomington. It is quite uniform in quality and has been used a great deal in pavement foundations and brickwork but has been considered unfit for concrete on account of its "dirty" condition. It actually contains 8.0% of suspended matter, but the tensile tests (see Table 1, pp. 44.) shows that it makes a stronger mortar than several of the very cleanest sands tested. It is fairly well graded as shown by the sieve analysis (see Plate 7.) and is rather coarse, 69.9% passing the No.16 sieve. The specific gravity is 2.625, the weight per cu. ft. 113.8 lb. and the percentage of voids 30.7 .

FIG. 7.

<u>Sample No. 8</u>. (Fig. 8.) This is a bank sand from near Rockford. The deposits are large and quite uniform in quality. The sand is light gray in color and contains considerable chert with some limestone and flint. The sieve analysis (see Plate 8) shows it to be fairly well graded. The amount of suspended matter is 0.6%, the specific gravity 2.665, the weight per cu. ft. 113. lb., and the percentage of voids. 32.0 .

FIG. 8.

Sample No. 9. (Fig. 9.) This is a sample of the sand used in the construction of the Supreme Court Building at Springfield and is a bank sand from near Lincoln. It is dark gray in color and nearly half of it is composed of flint, granite and limestone. The grains are all well rounded. It is fairly well graded (see Plate 9.), 65.8% passing the No.16 sieve and 6.5% the No. 60. There is 1.1% of suspended matter, principally clay, which adheres to the grains. The specific gravity is 2.65, the weight per cu. ft. 111.9 lb., and the percentage of voids 32.4 .

FIG. 9.

Sample No. 10. (Fig. 10) This is a bar sand from near Alton. It is dark gray in color and contains some flint granite and limestone. There is but 0.3% of suspended matter. The sieve analysis (see Plate 10.) shows it to be very fine, 90.3% passing the No.16 sieve. The specific gravity is 2.63, the weight per cu.ft. 112.5 lb., and the percentage of voids 31.5 .

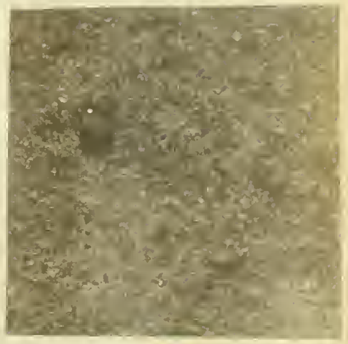


FIG. 10.

Sample No. 11. (Fig. 11.) This is also a bar sand from near Alton. It is brownish gray in color and contains some flint and limestone. There is also a small amount of coal and cinders present, probably as the result of transportation. The finer grains are well rounded but the coarser grains are more angular than usual. The sieve analysis (see

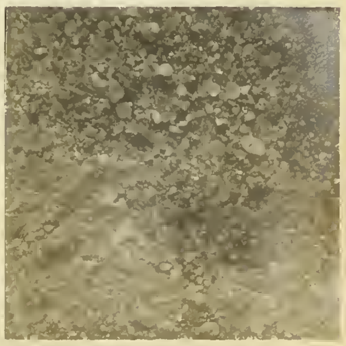


FIG. 11.

Plate 11) shows this sand to be quite fine, 80.0% passing the No.16 sieve. The amount of suspended matter is 0.2%, the specific gravity 2.66, the weight per cu. ft. 114.5 lb., and the percentage of voids 31.0

FIG. 12.

Sample No. 12. (Fig. 12.) This sand, used in large quantities in and about the cities of Champaign and Urbana, is a bank sand from along the Wabash River near Covington, Ind. It is of a yellowish gray color and contains some flint, limestone and shale. The grains are all well rounded. The sieve analysis (see Plate 12) shows this sand to be fairly well graded and rather coarse, the excess of material being between the No.8 and No.16 sieves. There is 1.5% of suspended matter, principally clay which does not adhere to the grains. The specific gravity is 2.66, the weight per cu. ft. 110.4 lb., and the percentage of voids 33.5 .

FIG. 13.

Sample No. 13. (Fig. 13.) This is a bank sand from near Gladstone. It is gray in color and contains some granite and flint. The grains are all moderately angular. It is quite fine, 97.9% passing the No.16 sieve and 12.9% the No.60. (See Plate 13.) This is the cleanest of the bamk sands there being but 0.2% of suspended matter. The specific gravity is 2.655, the weight per cu. ft. 106.3 lb., and the voids 35.8%.

Sample No. 14. (Fig. 14.) This sand is screened from bank gravel found along the Sangamon River near Decatur. It is brownish gray in color and contains considerable flint, granite, limestone, shale and ocherous rocks. A considerable portion of the grains are rather soft and were actually ruptured in the tensile tests. In spite of this the sand shows the second highest tensile strength and if the grains were harder would undoubtedly yield the strongest mortar. There is 2.5% of suspended matter but the tensile strength is not appreciably affected by washing. The sieve analysis curve as shown by Plate 14 lies the nearest to parabola and the percentage of voids is the lowest with the exception of the limestone screenings (Sample No.4) and Sample No. 21. The specific gravity is 2.66, the weight per cu. ft. 115.8 lb., and the percentage of voids 30.3 .

FIG. 14.

Sample No. 15. (Fig. 15.) This is a bank sand from near Freeport. It is yellow in color due to 1.3% of clay which adheres quite tightly to the grains. It contains some flint, limestone, and granite. The sieve analysis (see Plate 15) shows the sand to be moderately fine, 82.5% passing the No.16 sieve. The specific gravity is high (2.72) and the grains are quite hard although well rounded and if washed to break the coating of clay this would likely be an excellent sand. The weight per cu. ft. is 113.9 lb. and the percentage of voids 33.0

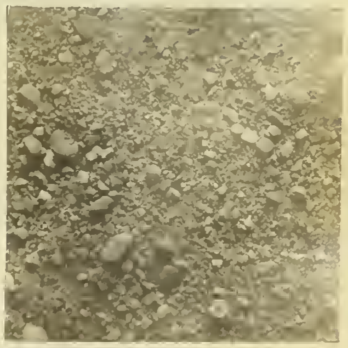


FIG. 15.

FIG. 16.

Sample No. 16. (Fig. 16.) This is a sample of Freeport Sandstone screenings. The stone is rather soft which probably accounts for the comparatively low tensile strength, (269 lb. at 90 days) the fragments frequently being ruptured in the test. The sieve analysis (see Plate 16.) shows this sample to be deficient in very fine material, only 4.2% passing the No.60 sieve. There is no suspended matter and the lack of fine material is due to the stone being composed of fine quartz sand cemented together and in the crushing the grains are simply separated and not broken up. The specific gravity is 2.705, the weight per cu.ft. 112.2 lb., and the percentage of voids 33.3 .

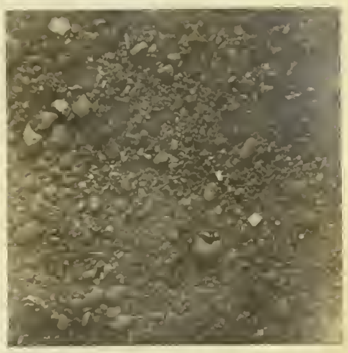


FIG. 17.

Sample No. 17. (Fig. 17.) This sand is screened from a bank gravel found near Aurora. It is yellowish in color and contains some shale. The grains are rounded and are coated with the suspended matter of which there is 0.5%. The sieve analysis (see Plate 17.) indicates that while not well graded this sand is comparatively coarse, 61.3% passing the No.16 sieve. The specific gravity is 2.72, the weight per cu. ft. 111.7 lb., and the percentage of voids 34.2 .

Sample No. 18. (Fig. 18a.) (See Sample No. 18W also) This sand comes from the Fuller Pit near Joliet and presents some rather unusual characteristics. The color is reddish yellow, due to the large amount of clay present. The grains appear quite

uniform in size and rounded in shape. The sieve analysis (see Plate 18.) shows that the greater part of the material lies between the No.20 and the No.60 sieves. Below the No.40 sieve the curve follows the parabola quite closely and in addition lies on the outside of it, being quite exceptional in this respect. This is undoubtedly due to the extremely large amount of suspended matter (18.3%) present in the sand. This suspended matter is almost entirely composed of clay and adheres very tightly to the grains, fully half of it normally coating them, making it almost impossible to determine the composition. On wetting the clay becomes gummy and the loose portion unites with the other making it impossible to wash the suspended matter out without thoroughly scrubbing it. The specific gravity is 2.66, the weight per cu. ft. 100.2 lb., and the percentage of voids 39.7 .

FIG. 18a.

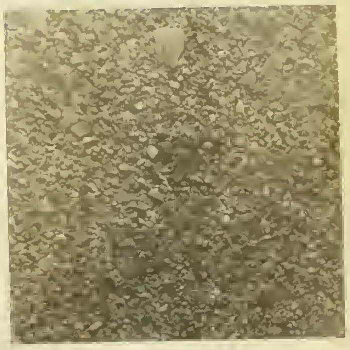


FIG. 18b.

Sample No. 18W. (Fig. 18b.) This sand is the same sand as Sample No. 18 with the exception that it has been thoroughly washed (18.3% removed). In washing it undergoes quite a visible change, apparent to some extent in the photographs. (Compare Figs. 18a and 18b.) The color changes to gray and the grains are shown to be quite irregular in shape. In fact this is the sharpest of the sands tested with the exception of Sample No. 21. There is considerably less quartz than usual, fully half of the grains consisting of limestone, granite, shale and ocherous rocks,

there being quite a considerable amount of soft material. The tensile test of the unwashed sand gives quite low results on account of the soft material and the large amount of clay. The tensile strength of the washed sand is about 35% higher than that of the unwashed sand and would doubtless be still higher were it not for the soft materials in the sand.

Sample No. 19. (Fig.19.) This is a bar sand from the Mississippi River a few miles above Moline. The bars are constantly shifting and hence the sand is more or less variable in character. It is gray in color and is composed principally of quartz with some flint, limestone, and granite. Referring to the sieve analysis (see Plate 19.) it will be noted that the sand is quite fine, 88.6% passing the No.16 sieve, but that there is a decided deficiency of very fine material, there being no suspended matter and but 0.2% passing the No.100 sieve. The specific gravity is 2.65, the weight per cu. ft. 112.0 lb., and the voids 32.3%.

FIG. 19.

Sample No. 20. (Fig. 20.) This sand, obtained from banks near Urbana, is quite variable in character but the sample used was fairly representative. It is yellowish in color and contains some granite, flint and chert. The grains are rounded and coated to a considerable extent with clay of which there is

FIG. 20.

The sieve analysis (see Plate 20.) shows this sand to be composed of about 80% of uniformly graded

material smaller than the No.30 sieve and 20% of coarser material also uniformly graded. The sand shows quite a tendancy to form lumps on drying but when wet behaves a good deal like quick-sand. The use of this sand has been almost abandoned on account of its variable character, the limited deposits and the shipping in of a good sand (Sample No.12.) at a price to compete with it. The specific gravity is 2.65, the weight per cu. ft. 107.5 lb., and the percentage of voids 35.0 .

<ins>Sample No. 21.</ins> (Fig. 21.) This sand is dredged from the bed of the Mississippi River at East St. Louis and varies but little in character. It is gray in color and contains some granite and flint. This is the sharpest of the natural sands, the grains being quite irregular in shape and the edges but slightly rounded. The grains are quite smooth, those of quartz (forming the greater part of the sand) being quite transparent with glassy surfaces. The sieve analysis (see Plate 21.) shows that this sand is not as well graded as some of the others but in spite of this it has the lowest percentage of voids. The specific gravity is 2.65, the weight per cu. ft. 115.8 lb., and the voids 30.1%.

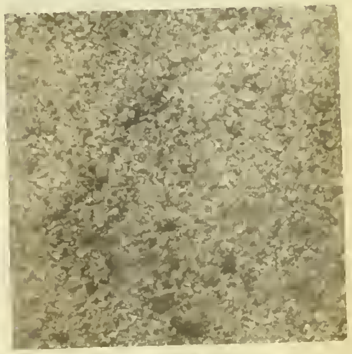


FIG. 21.

<ins>Sample No. 22.</ins> (Fig. 22.) This sand is taken from the shore of Lake Michigan near Waukegan. The character of this sand varies from time to time as the result of storms. This sample is dark gray in color and shows quite a variety of different components. The

FIG. 22.

principal ones are quartz, flint, limestone, granite, sandstone, shale, cinders, and coal. The last two are present to such an extent as to indicate that their presence is due to some other cause than transportation. There is barely a trace of suspended matter. The sieve analysis (see Plate 22.) shows this sand to be quite fine, 85.8% passing the No.16 sieve. The specific gravity is 2.68, the weight per cu. ft. 112.5 lb., and the voids 32.7%.

FIG. 23.

Sample No. 23. (Fig. 23.) This is a bank sand from limted but fairly uniform deposits near Paris. As shown by the sieve analysis (see Plate 23) this sand is very fine, 98.1% passing the No.16 sieve, there being but an occasional large grain. It is very light yellow in color and contains some limestone and chert with 1.2% of suspended matter. The grains are all well rounded. The specific gravity is 2.665, the weight per cu. ft. 108.3 lb., and the percentage of voids 35.2.

FIG. 24.

Samplo No. 24. (Fig. 24.) This is a bank sand from limited but vary uniform deposits near Taylorville. The mortar made of this sand is reported as working best when the proportion of cement is small and a great deal of this kind has been used but as might be expected has not proved durable. The sand is light yellow in color, the grains being quite rounded and composed principally of quartz with some limestone and shale. As shown by the sieve analysis (see Plate 24.) this is the finest sand tested, 100% passing the No.16 sieve, 99.5% passing the

No.40 sieve, and 75.4% passing the No.60 sieve. It is also the lightest sand, its weight per cu. ft. being but 99.7 lb. There is 4.0% of suspended matter and the sand shows a decided tendancy to lump on drying. The specific gravity is 2.635 and the voids 39.4%

Sample No. 25. (Fig. 25.) This sand, furnished by the Halliday Sand Co. of Cairo, comes from the bed of the Ohio River near that city. It is gray in color and contains some granite and limestone, the grains being somewhat rounded. According to the sieve analysis (see Plate 25) it is moderately fine, being deficient in both coarse and very fine grains. The suspended matter amounts to 0.3%. The specific gravity is 2.645, the weight per cu. ft. 107.8 lb., and the voids 34.7%.

FIG. 25.

Sample No. 26. (Fig. 26.) This is a sand from the Mississippi River at Hannibal, Mo. It is bluish gray in color and contains considerable flint, granite, and chert, the grains being moderately round. The sieve analysis (see Plate 26.) shows that it is deficient in both coarse and very fine grains. There is but 0.2% of suspended matter. The specific gravity is 2.68, the weight per cu. ft. 115.0 lb., and the percentage of voids 31.3 .

FIG. 26.

Sample No. 27. (Fig. 27.) This is a bank sand from deposits of variable character near Beardstown. It is reddish yellow in color due to 4.4% of reddish clay which adheres to the grains. It contains some granite, limestone, and flint and shows a tendency

to form lumps. The sieve analysis (see Plate 27.) shows that it is extremely fine, practically all passing the No.16 sieve, and 47.4% passing the No.60 sieve. It is next in fineness to Sample No. 24. This sand has been used a great deal and has given fairly satisfactory results. The specific gravity is 2.605, the weight per cu. ft. 101.0 lb., and the percentage of voids 37.9 .

FIG. 27.

Sample No. 28. (Fig. 28.) This sand is from the Wabash River near Mt. Carmel. It is yellowish gray in color and contains some flint, granite and cinders. The sieve analysis (see Plate 24.) shows it to be almost as fine as Sample No. 27. It is the finest and also the dirtiest river sand tested, there being 2.4% of suspended matter. The grains are all well rounded. The specific gravity is 2.635, the weight per cu. ft. 104.9 lb., and the percentage of voids 36.5 .

FIG. 28.

Sample No. 29. (Fig. 29.) This is a bank sand from along the Little Vermillion River above LaSalle. It is gray in color and is composed almost entirely of quartz, the grains all being well rounded. The sieve analysis (see Plate 29.) shows it to be very fine, 99.3% passing the No.16 sieve and 26.0% the No.60. There is 3.2% of suspended matter. The specific gravity is 2.65, the weight per cu. ft. 106.7 lb., and the voids 35.5%.

FIG. 29.

Sample No. 30. (Fig. 30.) This sand is from the Crescent Gravel Pit near Peoria. It is yellowish gray in color and contains some shale, flint, and granite. The grains are rounded and quite fine, 90.3% passing the No.16 sieve and 17.8% the No. 60.(see Plate 30) There is 2.7% of suspended matter. The specific gravity is 2.665, the weight per cu. ft. 111.9 lb. and the percentage of voids 32.9 .

FIG. 30.

Sample No. 31. (Fig. 31.) This sand was taken from a large sewer trench near the center of the city of Peoria. It is yellowish gray in color and contains some flint, granite, limestone and chert. The medium sized grains are the more angular. There is 1.9% of suspended matter and the sieve analysis (see Plate 31) shows the sand to be quite fine, 86.5% passing the No.16 sieve. The specific gravity is 2.64, the weight per cu. ft. 108.7 lb., and the percentage of voids 36.9 .

FIG. 31.

Sample No. 32. (Fig. 32.) This is a bar sand from the Illinois River above Peoria. It is brownish gray in color, about half of the grains are quartz, the remainder being flint, limestone, granite, chert, and cinders. The suspended matter amounts to 0.6%. The sieve analysis (see Plate 32) shows this sand to be very fine, 97.1% passing the No.16 sieve. The specific gravity is 2.66, the weight per cu. ft. 108.7 lb., and the voids 34.6%.

FIG. 32.

SUMMARY OF CHARACTERISTICS.

Composition. The sands used in the important cities of Illinois are, almost without exception, composed of minerals which are quite hard and durable. Some few samples contain an appreciable amount of soft material, although in each case this soft material appears to be of such a character as to reduce the strength of the mortar without affecting its durability. By far the greater number of samples contain a very large proportion of quartz, but the other materials present are usually equally good.

Specific Gravity. The specific gravity of the sands varies from about 2.60 to 2.72. Sands composed almost entirely of quartz have a specific gravity of 2.65 to 2.66. Other materials than quartz affect the specific gravity of the sands in proportion to their amount and character, but the determination of the specific gravity gives little information concerning this. However, if the specific gravity is greater than 2.66 it is probable that all of the materials are hard and durable; whereas if the specific gravity is less than 2.65 the chances are that there is some soft and undesirable material present.

Sharpness. The sands vary in sharpness from the standard sand with its regular shaped, almost globular grains, to Sample No.21 with its grains of great irregularity whose edges are but slightly rounded by wear. The greater number of sands show a degree of sharpness about midway between these two extremes. The sharpness, however, appears to have little or no effect on the tensile strength of the mortar.

Fineness. Almost all of the sands are quite fine, only two or three samples even approximating an ideal grading, and several being extremely fine. There is a universal deficiency of coarse grains and in several cases a deficiency of very fine material also. These deficiencies are made up by and excess of grains from 0.007 to 0.02 in. in diameter (between sieves No.74 and 30.) This excess of material is composed almost entirely of quartz and all of the quartz sands are quite fine. There is but a small amount of quartz grains which would be retained on a No.16 sieve. The coarse grains are invariably of materials which are harder and less easily crushed than the quartz.

Cleanness. The sands are, on the average, quite clean, in one case only is there sufficient suspended matter to have any considerable effect on the mortar. For the most part the river and lake sands are much cleaner than the bank sands, the average amount of suspended matter in the former being but about 0.3% and in the latter about 2.2% (omitting Sample No.18.) A number of tests on the effect of washing the sands indicate that the suspended matter present had no appreciable effect on the strength of the mortar except in the cases of Samples No.7 and 18.

Crushed Stone Screenings. The tests on the two samples of crushed stone screenings indicate that this material is the equal if not the superior of the best natural sands. The limestone screenings gave the strongest mortar tested and the sandstone screenings a strength quite comparable with the natural sands. The presence of more coarse material and the greater roughness of the particles undoubtedly tend to increase the strength.

Specifications. Tho ordinary specifications that sand shall be "clean, sharp, and coarse" are not sufficient to secure the bost sand. The terms used are too indefinite to allow of rigid enforcement or even of a fairly reliable interpretation. Moreover it is likely that the sand will be judged by its apparent cleanness and sharpness and the coarseness not given due weight, whereas these tests show that the sharpness is of relatively small importance and that cleanness is secondary to composition and gradation of sizes. Specifications should therefore be written to cover the composition, fineness, and cleanness, giving definite limits for each of these, in order that the specifications may serve the purpose for which they are intended.

Illinois Sands. Samples No. 14, 5, and 17 are, in order, the best graded sands tested, and as would be expected yield the strongest mortars. They are composed entirely of hard, durable minerals with the exception of Sample No.14 which contains some soft material and as a result ranks third in strength in place of first. These sands are the best sands tested and are quite satisfactory for all classes of work.

Sample No. 7 is the next to the dirtiest sand tested, it containing 8.0% of suspended matter. It contains some soft material but not enough to impair the strength. A thorough washing increased the strength but about 8.0% at 28 days and as commercial washing is not likely to be as efficient as the laboratory washing and therefore it would probable not be advisable to attempt to wash it in practice. This sand yields a mortar which is fairly strong and it therefore appears that this sand does not merit its name of "too dirty for concrete".

Sample No.18. is the poorest in quality of all the sands tested, combining as it does poor grading with a large amount of soft material and an abnormal amount of suspended matter (18.3%) The strength of the mortar is very low and although a thorough washing increased it about 35% it is still comparatively low. It would therefore be economical to entirely abandon the use of this sand and import a good sand from elswhere, and in this case a good sand (Sample No.17.) is obtainable within a short distance.

Samples No.1, 23, 24, 27, 28, and 29 are all quartz sands of extreme fineness. They are excellent sands for concrete block facings and similar purposes where a smooth finish is desired and for grout filler but they yield a mortar which is too weak for general work. It would therefore be much more economical for these cities to import good coarse sands for concrete work.

All of the remaining samples are composed of first class materials but are, on the average, too fine for the best results. All of them, however, could be greatly improved by mixing a judicious amount of coarse material with them and it would doubtless be good policy to import at least sufficient good sand for this purpose.

C O N C L U S I O N .

While this series of tests does not include all of the sands in common use in the important cities of Illinois, a sufficient number have been tested to furnish information concerning the mortar making qualities of sands available in various sections of the state.

The results show that the sands from any locality may be quite variable in their mortar making qualities, and that the variation may be so great that a stronger mortar per unit of cost may often be obtained by substituting a lean mixture of one sand for a rich mixture of another even though the first sand may be considerably the more expensive. For example, Sample No. 18 yields a mortar very much weaker than Sample No.17 (see Table 1, p.49.) and in accordance with the laws of proportioning (see page 4.) would require a very rich mixture, probably richer than a 1:1, to equal No.17 in strength. Since the saving in cement by changing from a 1:1 to a 1:3 mixture amounts to considerably more than a barrel per cubic yard of sand it is evident that Sample No.17 could be substituted for Sample No.18, even at a very considerable increase in cost per cubic yard and the resulting mortar still be stronger per unit of cost than if Sample No. 18 were used. Several such examples can be found among the sands tested and therefore a comparison of the results should serve as an index to the engineer as to when the local sand will prove satisfactory or when he would probably be justified in obtaining sand from other localities, even at considerable cost.

The results show further that the choice of the best sand

is a problem which requires care, good judgment, and a knowledge of the sands available. In important work, where the best mortar obtainable ir required, an investigation of the available sands would doubtless be well worth the time and expense required to make it.

TABLE 1

TENSILE STRENGTH – 1:3 MORTAR.

SAMPLE No	NAME	AGE DAYS	TENSILE STRENGTH – POUNDS PER SQ. IN.						
			INDIVIDUAL BRIQUETTES						AVERAGE
00	Neat Cement	7	615	645	640	690	620	–	642
		28	780	730	770	760	720	–	772
		90	755	820	785	780	–	–	785
0	Ottawa Standard 20-30	7	220	200	220	230	230	–	225
		28	310	300	315	340	315	295	313
		90	375	365	375	370	360	365	368
1	Chicago K. I. Co.	7	115	110	108	113	108	–	111
		28	205	195	190	200	165	195	192
		90	210	210	210	190	205	–	205
2	Chicago Z-R. Co.	7	150	175	175	145	150	–	159
		28	300	260	275	290	250	270	274
		90	315	310	330	290	–	–	311
3	Chicago K. I. Co.	7	200	220	205	170	180	–	195
		28	265	295	260	270	305	290	281
		90	320	310	320	305	315	–	314
4	Joliet Limestone Screenings	7	220	240	200	210	220	–	218
		28	295	335	365	350	330	–	335
		90	450	530	505	460	–	–	485
5	Elgin Hammond Pit	7	245	270	240	220	250	–	245
		28	380	375	395	425	410	380	394
		90	465	455	450	445	490	480	464
6	Elgin Stimpson Pit	7	190	180	210	225	210	200	203
		28	340	340	360	350	390	–	356
		90	415	420	405	400	–	–	410
7	Bloomington.	7	225	230	225	235	210	225	225
		28	225	265	250	240	235	260	246
		90	295	305	275	285	270	–	286
8	Rockford	7	250	240	260	230	245	265	248
		28	335	345	350	335	330	340	339
		90	385	380	410	360	395	385	386
9	Lincoln	7	235	220	230	210	200	205	217
		28	285	270	275	285	275	290	279
		90	310	310	290	300	300	305	303
10	Alton	7	185	180	175	185	150	175	175
		28	245	230	250	255	220	260	243
		90	275	270	260	270	270	270	269

TABLE 1

TENSILE STRENGTH – 1:3 MORTAR.

SAMPLE Nº	NAME	AGE DAYS	TENSILE STRENGTH – POUNDS PER SQ. IN. INDIVIDUAL BRIQUETTES						AVERAGE
11	Alton	7	180	195	210	195	190	–	194
		28	245	235	250	245	240	–	243
		90	270	285	295	280	270	280	280
12	Covington Ind.	7	205	185	200	200	205	195	198
		28	265	280	250	280	285	245	267
		90	315	315	310	305	315	300	310
13	Gladstone	7	190	180	180	170	170	180	178
		28	230	220	205	210	225	220	218
		90	250	235	240	230	240	250	241
14	Decatur	7	270	310	285	285	305	265	287
		28	380	375	355	355	360	–	365
		90	425	435	420	430	430	–	428
15	Freeport	7	245	205	200	220	190	225	214
		28	275	285	270	260	265	265	270
		90	335	330	320	315	310	295	317
16	Freeport Sandstone Screenings	7	180	180	195	220	170	195	190
		28	220	250	240	210	250	235	234
		90	235	260	270	270	300	280	269
17	Aurora	7	270	290	260	270	270	–	272
		28	390	415	400	435	410	–	410
		90	470	460	450	450	440	–	454
18	Joliet	7	120	130	98	100	100	100	108
		28	100	105	125	115	140	160	124
		90	145	170	155	150	150	175	159
18W	Joliet (Washed)								
		28	150	170	190	175	185	185	176
19	Moline	7	160	180	175	170	160	180	171
		28	250	225	235	245	–	–	239
		90	275	260	260	245	240	265	257
20	Urbana	7	190	185	190	200	200	195	193
		28	240	240	230	220	245	265	240
		90	365	320	315	310	340	330	330

TABLE 1.

TENSILE STRENGTH.

SAMPLE Nº	NAME	AGE DAYS	TENSILE STRENGTH - POUNDS PER SQ. IN.						
			INDIVIDUAL BRIQUETTES						AVERAGE
21	E. ST. LOUIS	7	170	185	170	160	170	175	172
		28	195	210	205	190	210	230	207
		90	285	275	230	245	245	265	258
22	WAUKEGAN	7	140	145	160	175	155	140	158
		28	235	230	225	225	230	220	228
		90	300	270	280	310	305	310	296
23	PARIS	7	125	130	120	130	120	115	123
		28	200	200	200	205	190	190	198
		90	260	245	285	265	245	255	259
24	TAYLORVILLE	7	110	100	100	115	130	135	113
		28	140	155	150	155	135	160	149
		90	210	220	195	220	200	220	211
25	CAIRO	7	155	155	140	155	175	140	153
		28	260	210	235	220	245	240	234
		90	300	295	300	325	280	285	298
26	HANNIBAL, MO.	7	160	150	150	175	175	180	165
		28	220	200	205	225	180	220	208
		90	290	270	290	275	275	275	279
27	BEARDSTOWN	7	95	80	90	90	90	70	86
		28	115	105	100	105	115	100	107
		90	145	130	150	135	135	145	140
28	MT. CARMEL	7	100	100	85	100	100	105	99
		28	140	135	130	140	125	140	135
		90	185	175	175	165	160	160	170
29	LA SALLE	7	130	120	130	110	100	110	117
		28	200	180	175	190	200	170	186
		90	175	200	185	190	210	200	194
30	PEORIA	7	195	170	180	185	170	170	178
		28	200	205	200	205	210	210	205
		90	235	260	265	260	280	270	262
31	PEORIA	7	165	140	175	185	150	185	167
		28	210	220	230	200	235	235	221
		90	315	320	295	285	320	300	306
32	PEORIA	7	120	110	105	105	115	125	114
		28	155	155	145	145	160	160	153
		90	185	170	190	180	165	180	178

TABLE 2.

SIEVE ANALYSIS.

SAMPLE No.	NAME	SUSPENDED MATTER	PERCENT BY WEIGHT PASSING SIEVE No.												
			200	150	100	74	60	40	30	20	16	10	8	5	0.2 in.
1	Chicago, K.I.Co.	0.3	–	–	4.2	48.6	69.5	96.4	99.1	99.7	99.8	–	100.0	–	100.0
2	do. Z-R.Co.	0.3	–	–	2.5	20.0	25.9	77.3	87.5	93.7	94.7	–	99.1	–	100.0
3	do. K.I.Co.	0.3	–	–	2.4	9.9	15.9	49.1	69.0	78.3	79.8	–	89.1	–	100.0
4	Limestone Scr.	0.0	–	–	8.1	9.3	10.7	14.9	15.5	19.9	21.2	–	52.3	–	100.0
5	Elgin	1.0	–	–	2.8	5.0	7.4	20.9	36.4	51.7	55.0	–	84.0	–	100.0
6	do.	0.9	–	–	2.1	5.2	9.0	23.6	39.2	60.1	65.5	–	97.3	–	100.0
7	Bloomington	8.0	9.0	9.7	11.4	19.8	21.7	43.0	56.5	67.2	69.9	85.8	92.1	96.6	100.0
8	Rockford	0.6	–	–	1.7	5.5	10.8	25.1	34.3	60.0	68.2	–	98.0	–	100.0
9	Lincoln	1.1	–	–	2.4	4.1	6.5	26.7	46.4	61.7	65.8	–	95.4	–	100.0
10	Alton	0.3	–	–	1.2	5.2	10.5	45.6	70.2	87.8	90.3	–	98.2	–	100.0
11	do.	0.2	–	–	2.2	5.3	8.9	30.1	53.8	76.2	80.0	–	97.0	–	100.0
12	Covington, Ind.	1.5	–	–	3.6	5.7	7.6	19.8	31.6	47.9	53.3	–	93.5	–	100.0
13	Gladstone	0.2	–	–	1.1	6.8	12.9	63.8	88.8	97.0	97.9	–	99.8	–	100.0
14	Decatur	2.5	2.9	3.1	3.9	6.0	7.8	21.0	35.8	45.9	48.7	71.6	81.5	93.7	100.0
15	Freeport	1.3	3.0	3.7	6.6	14.4	18.5	43.9	63.6	79.2	82.5	97.2	99.2	99.9	100.0
16	Sandstone Scr.	0.0	–	–	0.2	1.4	4.2	30.9	63.2	82.9	86.4	–	98.3	–	100.0
17	Aurora	0.5	–	–	0.9	1.1	1.6	12.3	35.0	55.7	61.3	–	97.8	–	100.0
18	Joliet	18.3	19.3	19.5	20.2	21.1	22.2	32.5	63.7	94.8	96.9	99.5	99.7	99.9	100.0
19	Moline	0.0	0.0	0.1	0.2	1.6	4.3	35.2	67.1	85.8	88.6	96.9	98.3	99.4	100.0
20	Urbana	3.5	6.7	8.6	17.0	39.1	52.4	74.4	79.6	83.5	84.5	92.3	95.3	98.3	100.0
21	E. St. Louis	Trace	0.4	0.7	1.8	5.9	9.9	39.5	55.1	79.4	82.6	95.9	97.8	99.4	100.0
22	Waukegan	0.0	0.1	0.2	0.8	8.8	12.1	38.4	61.7	82.0	85.8	98.0	99.0	100.0	100.0
23	Paris	1.2	1.7	2.1	4.3	12.9	16.9	64.4	91.4	97.6	98.1	99.1	99.4	99.8	100.0
24	Taylorville	4.0	7.4	9.4	22.1	55.6	75.4	99.5	99.8	99.9	100.0-	100.0-	100.0	100.0	100.0
25	Cairo	0.3	0.4	0.5	0.8	2.5	3.9	24.9	62.9	81.9	84.8	95.7	98.1	99.8	100.0
26	Hannibal, Mo.	0.2	0.3	0.4	0.9	3.9	7.4	33.2	58.5	76.9	80.4	93.3	96.1	99.3	100.0
27	Beardstown	4.4	6.6	7.6	13.2	35.3	47.4	97.0	99.6	99.9	100.0-	100.0-	100.0	100.0	100.0
28	Mt. Carmel	2.4	2.6	2.7	3.9	18.8	34.2	98.7	99.8	99.9	100.0-	100.0-	100.0	100.0	100.0
29	La Salle	3.2	4.2	4.5	6.8	16.5	26.0	87.6	97.7	99.1	99.3	99.7	99.8	99.9	100.0
30	Peoria	2.7	3.1	3.5	6.0	14.5	17.8	47.8	74.9	88.2	90.3	96.7	98.0	99.0	100.0
31	do.	1.9	2.3	2.4	2.6	3.0	4.0	20.0	59.5	83.6	86.5	96.2	97.9	99.3	100.0
32	do.	0.6	0.8	0.9	2.0	9.2	13.3	68.7	89.1	96.0	97.1	99.0	99.4	99.7	100.0

TABLE 3.

SPECIFIC GRAVITY – VOIDS – WEIGHT.

SAMPLE No.	NAME	D Water displaced by 100g. Sand Cu.Cm.	SPECIFIC GRAVITY $\frac{100}{D}$	S 500xSp.Gr.	W Weight of 500c.c. of Sand. Grams	VOIDS $\frac{S-W}{S}$ Percents	WEIGHT PER CU. FT. Pounds.
0	Standard	37.57	2.66	1330.0	870.0	34.6	108.7
1	Chicago, K.I.Co.	37.62	2.655	1327.5	847.0	36.2	105.8
2	do. Z-R.Co.	37.65	2.655	1327.5	871.0	34.4	108.8
3	do. K.I.Co.	37.13	2.695	1347.5	922.0	31.6	115.1
4	Limestone Scr.	36.40	2.75	1375.0	983.0	28.5	122.8
5	Elgin	36.69	2.72	1360.0	926.0	31.9	115.7
6	do	37.27	2.68	1340.0	916.0	31.6	114.4
7	Bloomington	38.10	2.625	1312.5	911.5	30.5	113.8
8	Rockford	37.51	2.665	1332.5	905.0	32.0	113.0
9	Lincoln	37.72	2.65	1325.0	895.5	32.4	111.9
10	Alton	38.03	2.63	1315.0	901.0	31.5	112.5
11	do.	37.57	2.66	1330.0	917.0	31.0	114.5
12	Covington, Ind.	37.60	2.66	1330.0	884.5	33.5	110.4
13	Gladstone	37.65	2.655	1327.5	852.0	35.8	106.3
14	Decatur	37.60	2.66	1330.0	927.5	30.3	115.8
15	Freeport	36.80	2.72	1360.0	912.0	33.0	113.9
16	Sandstone Scr.	36.97	2.705	1352.5	899.0	33.0	112.2
17	Aurora	36.75	2.72	1360.0	894.0	34.2	111.7
18	Joliet	37.60	2.66	1330.0	802.0	39.7	100.2
19	Moline	37.77	2.65	1325.0	897.0	32.3	112.0
20	Urbana	37.75	2.65	1325.0	861.0	35.0	107.5
21	E. St. Louis	37.73	2.65	1325.0	927.0	30.1	115.8
22	Waukegan	37.25	2.68	1340.0	901.0	32.7	112.5
23	Paris	37.52	2.665	1332.5	867.0	35.2	108.3
24	Taylorville	37.88	2.635	1317.5	798.5	39.4	99.7
25	Cairo	37.79	2.645	1322.5	863.0	34.7	107.8
26	Hannibal, Mo.	37.33	2.68	1340.0	921.0	31.3	115.0
27	Beardstown	38.40	2.605	1302.5	809.0	37.9	101.0
28	Mt. Carmel	37.90	2.635	1317.5	835.5	36.5	104.4
29	La Salle	37.70	2.65	1325.0	854.0	35.5	106.7
30	Peoria	37.50	2.665	1332.5	896.5	32.9	111.9
31	do.	37.80	2.64	1320.0	832.0	36.9	103.9
32	do.	37.61	2.66	1330.0	870.0	34.6	108.7

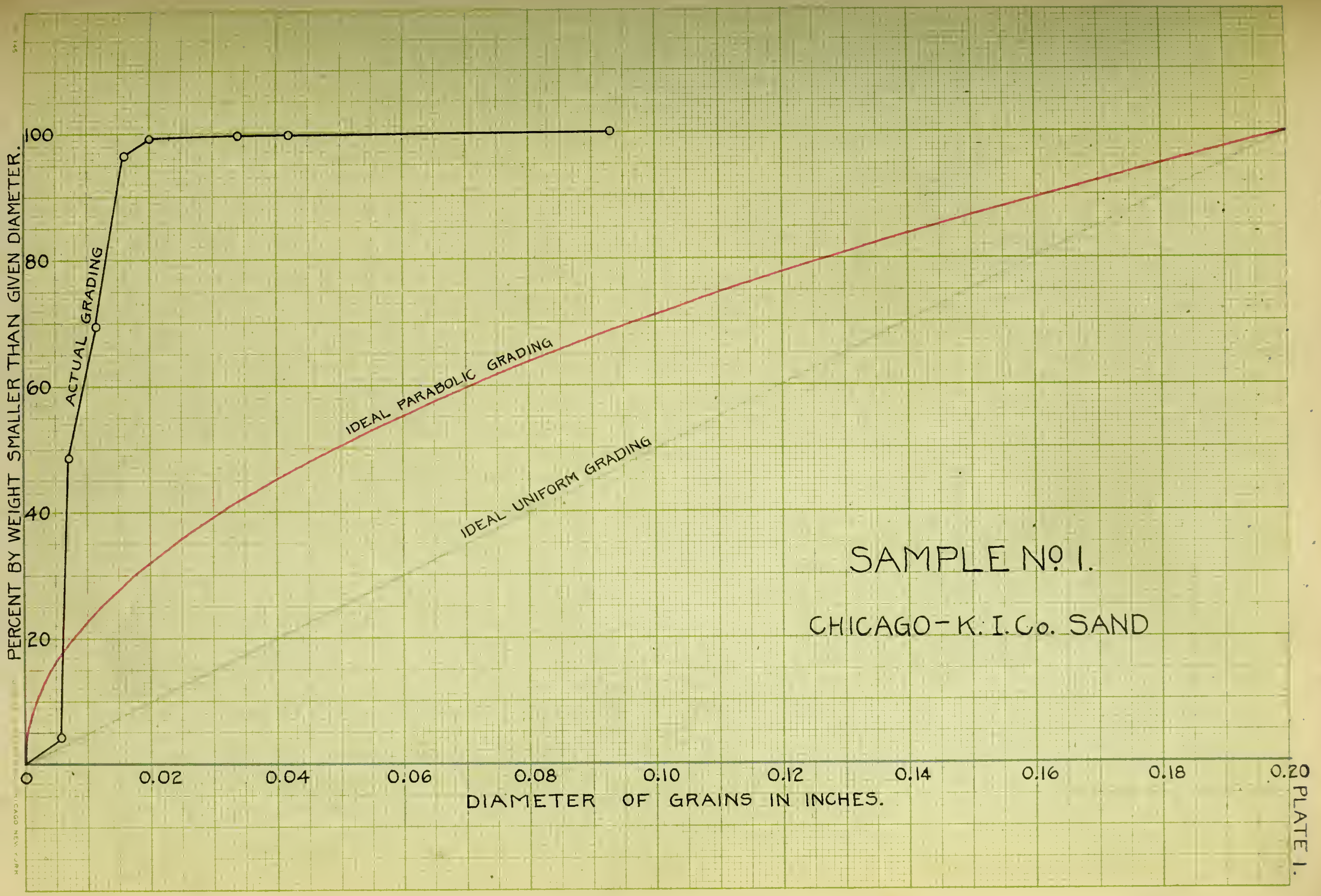


PLATE I.
SAMPLE No. I.
CHICAGO-K. I. Co. SAND
PERCENT BY WEIGHT SMALLER THAN GIVEN DIAMETER.
DIAMETER OF GRAINS IN INCHES.
ACTUAL GRADING
IDEAL PARABOLIC GRADING
IDEAL UNIFORM GRADING
0
20
40
60
80
100
0.02
0.04
0.06
0.08
0.10
0.12
0.14
0.16
0.18
0.20

PLATE 2.

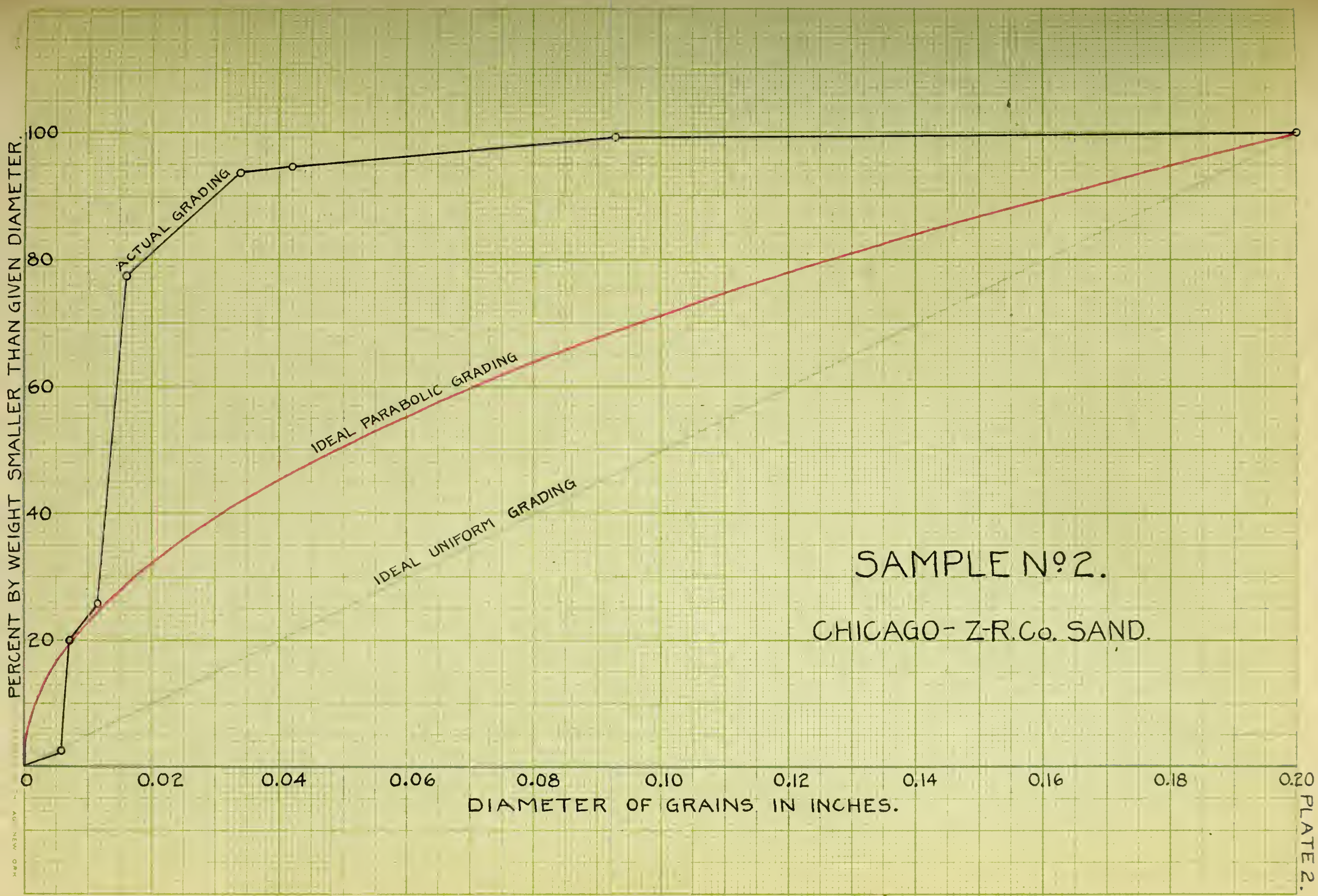

SAMPLE Nº 2.
CHICAGO - Z-R.Co. SAND.
ACTUAL GRADING
IDEAL PARABOLIC GRADING
IDEAL UNIFORM GRADING
PERCENT BY WEIGHT SMALLER THAN GIVEN DIAMETER.
DIAMETER OF GRAINS IN INCHES.
100
80
60
40
20
0
0.02
0.04
0.06
0.08
0.10
0.12
0.14
0.16
0.18
0.20

PLATE 3.

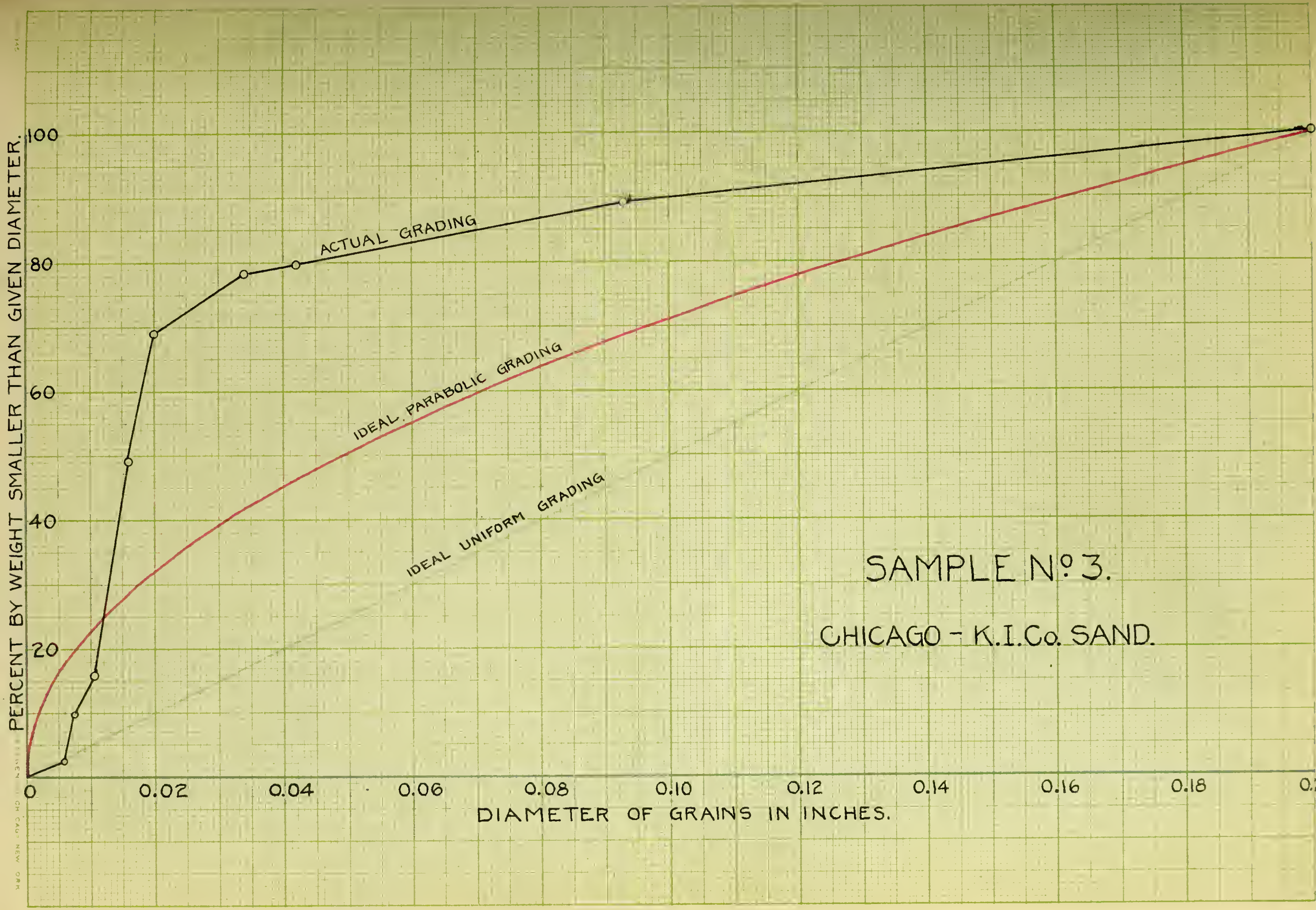
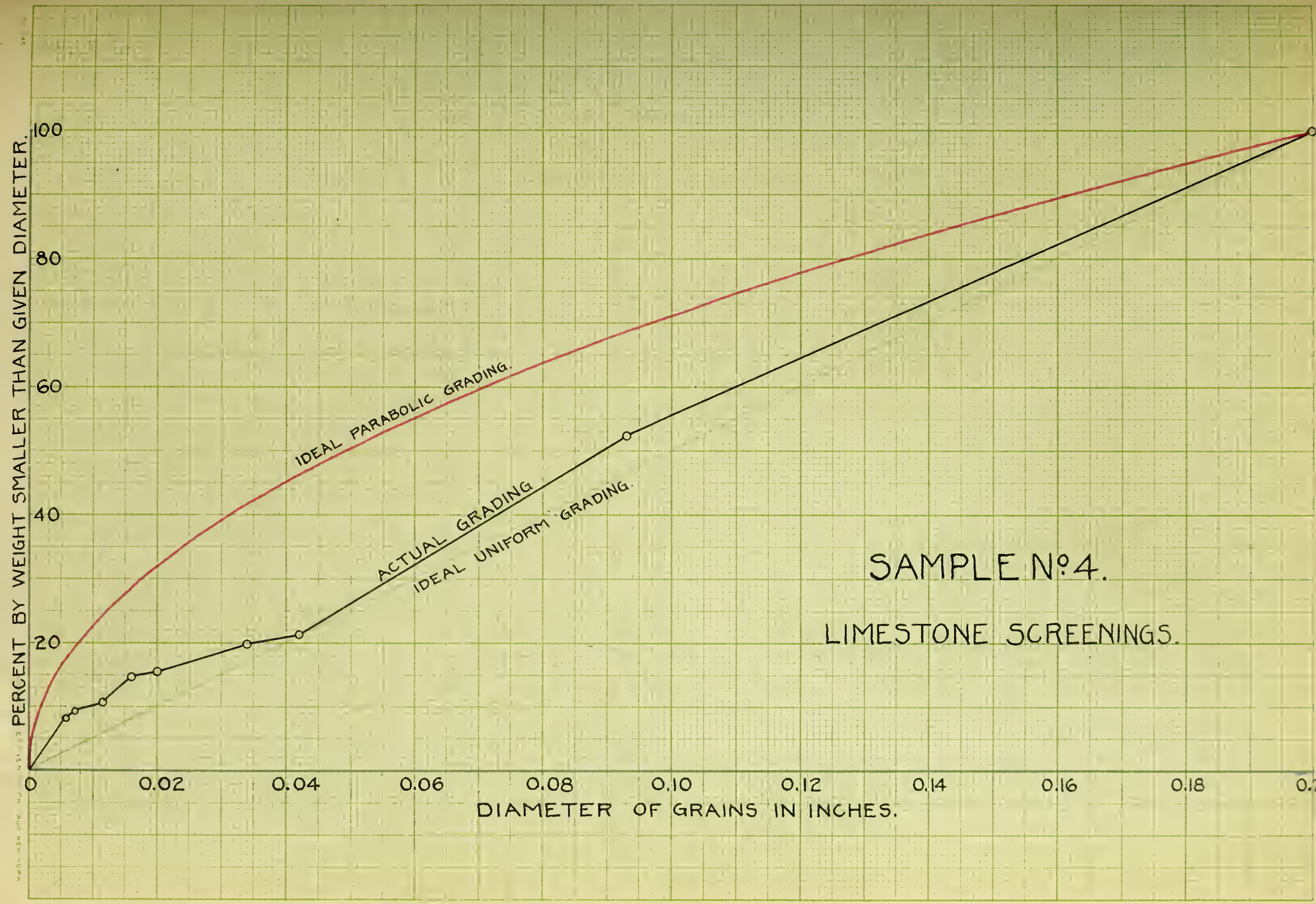

SAMPLE Nº 3.
CHICAGO - K.I.Co. SAND.
ACTUAL GRADING
IDEAL PARABOLIC GRADING
IDEAL UNIFORM GRADING
PERCENT BY WEIGHT SMALLER THAN GIVEN DIAMETER.
DIAMETER OF GRAINS IN INCHES.
0
20
40
60
80
100
0.02
0.04
0.06
0.08
0.10
0.12
0.14
0.16
0.18
0.20

PLATE 4.


SAMPLE Nº 4.
LIMESTONE SCREENINGS.
IDEAL PARABOLIC GRADING.
ACTUAL GRADING
IDEAL UNIFORM GRADING.
PERCENT BY WEIGHT SMALLER THAN GIVEN DIAMETER.
DIAMETER OF GRAINS IN INCHES.
100
80
60
40
20
0
0.02
0.04
0.06
0.08
0.10
0.12
0.14
0.16
0.18
0.20

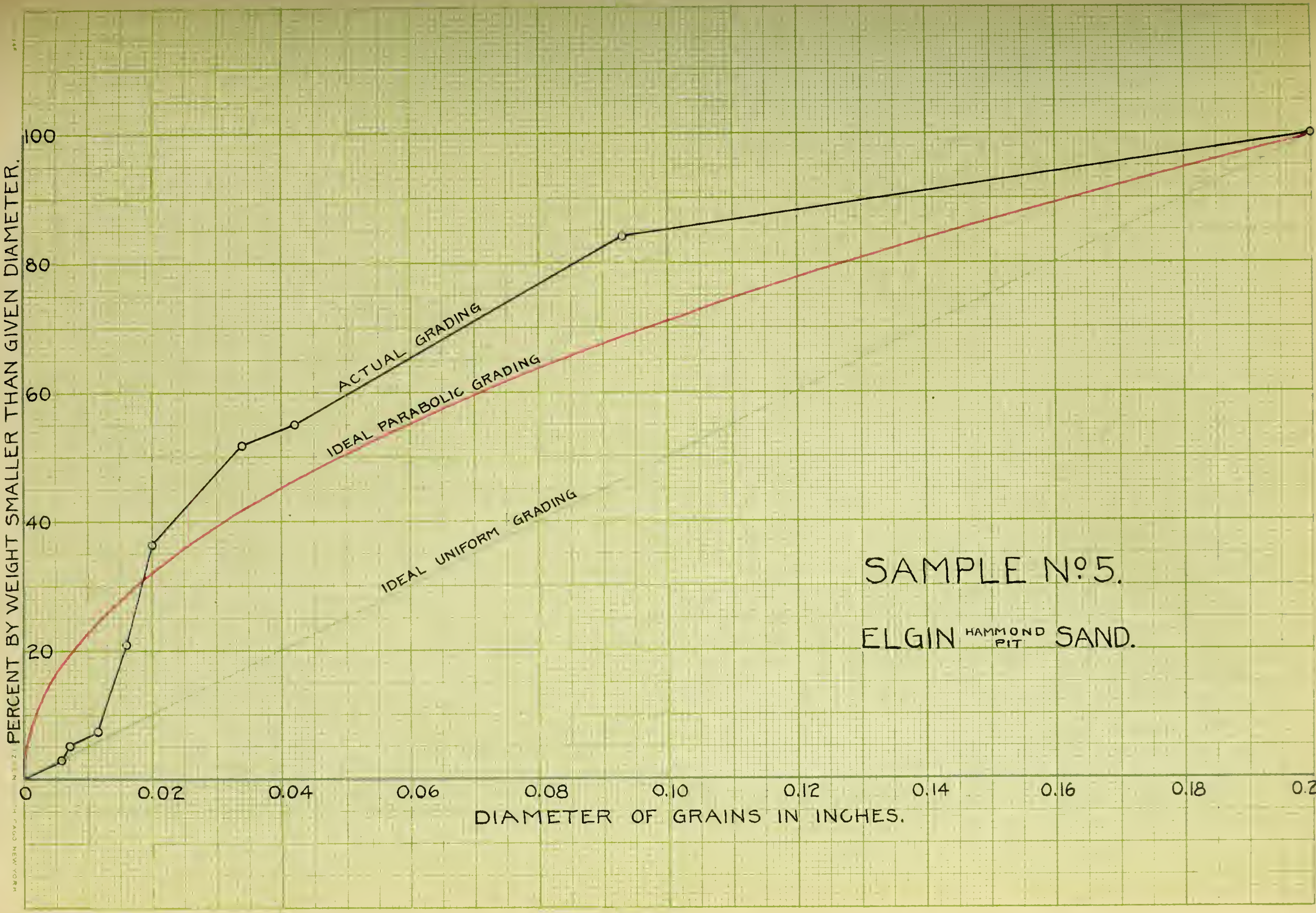

SAMPLE No. 5.
ELGIN HAMMOND PIT SAND.
ACTUAL GRADING
IDEAL PARABOLIC GRADING
IDEAL UNIFORM GRADING
PERCENT BY WEIGHT SMALLER THAN GIVEN DIAMETER.
DIAMETER OF GRAINS IN INCHES.
100
80
60
40
20
0
0.02
0.04
0.06
0.08
0.10
0.12
0.14
0.16
0.18
0.20

PLATE 6.

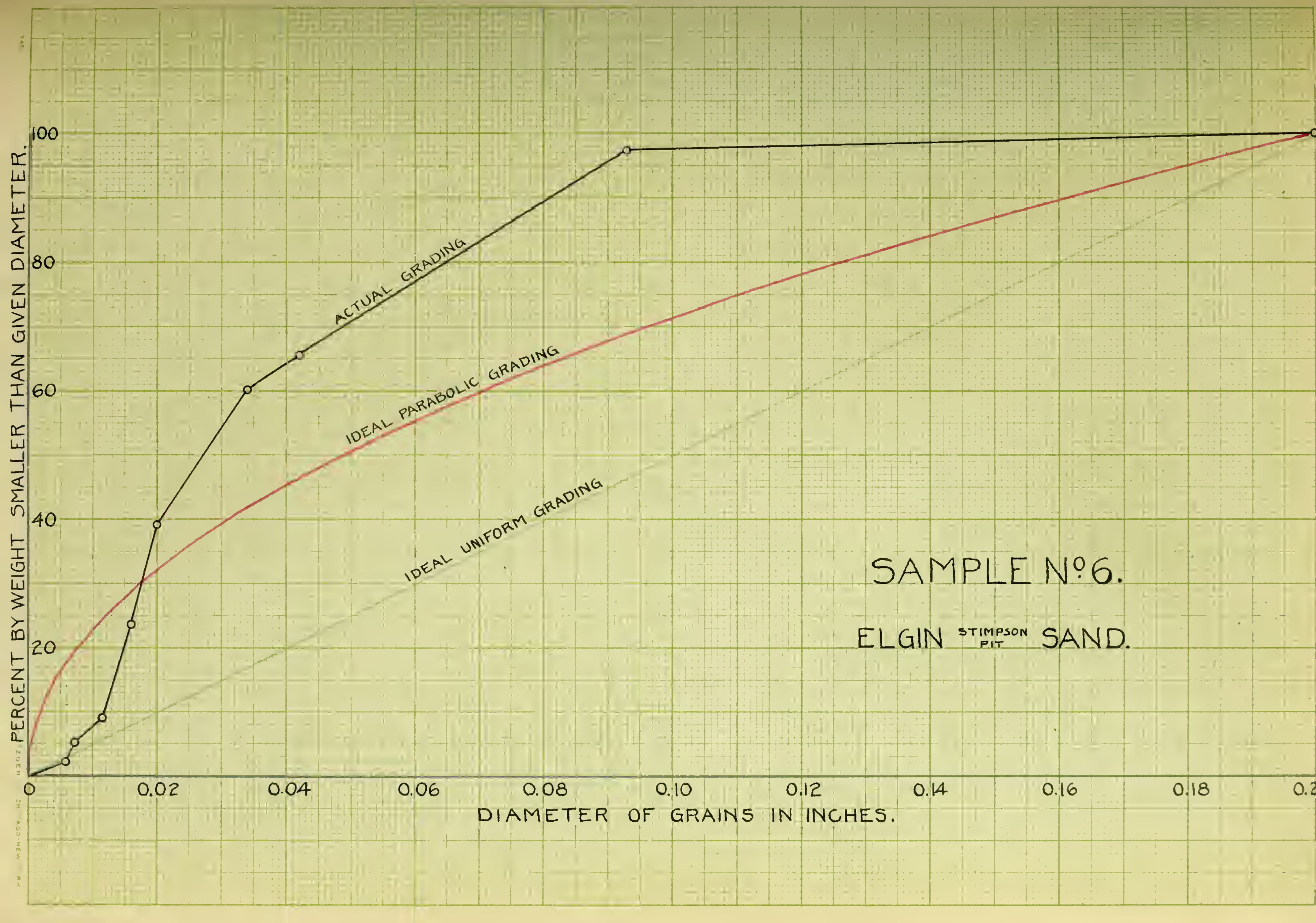

SAMPLE No. 6.
ELGIN STIMPSON PIT SAND.
ACTUAL GRADING
IDEAL PARABOLIC GRADING
IDEAL UNIFORM GRADING
PERCENT BY WEIGHT SMALLER THAN GIVEN DIAMETER.
DIAMETER OF GRAINS IN INCHES.
0
20
40
60
80
100
0.02
0.04
0.06
0.08
0.10
0.12
0.14
0.16
0.18
0.20

PLATE 7.

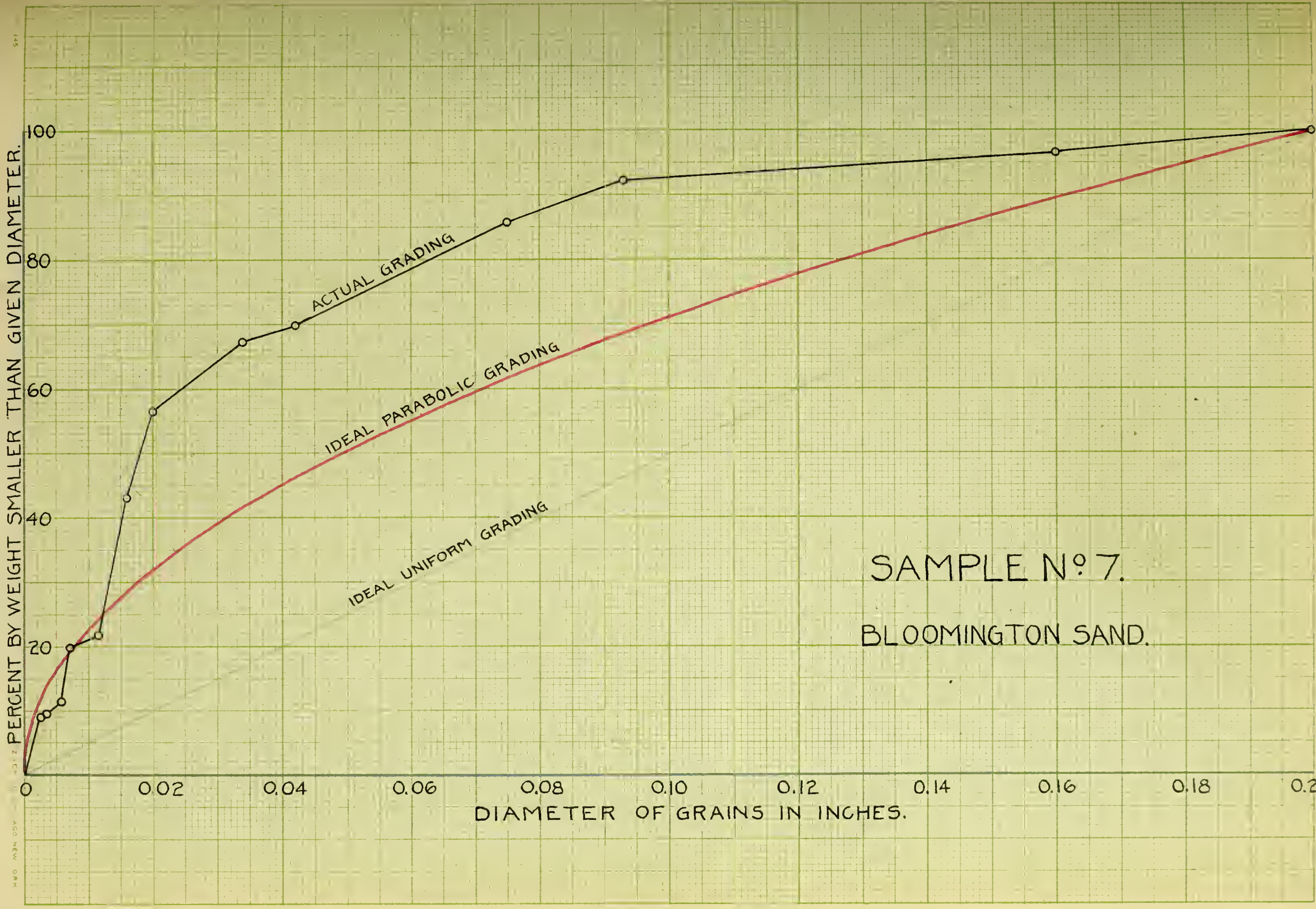

SAMPLE Nº 7.
BLOOMINGTON SAND.
ACTUAL GRADING
IDEAL PARABOLIC GRADING
IDEAL UNIFORM GRADING
PERCENT BY WEIGHT SMALLER THAN GIVEN DIAMETER.
DIAMETER OF GRAINS IN INCHES.
100
80
60
40
20
0
0.02
0.04
0.06
0.08
0.10
0.12
0.14
0.16
0.18
0.20

PLATE 8.

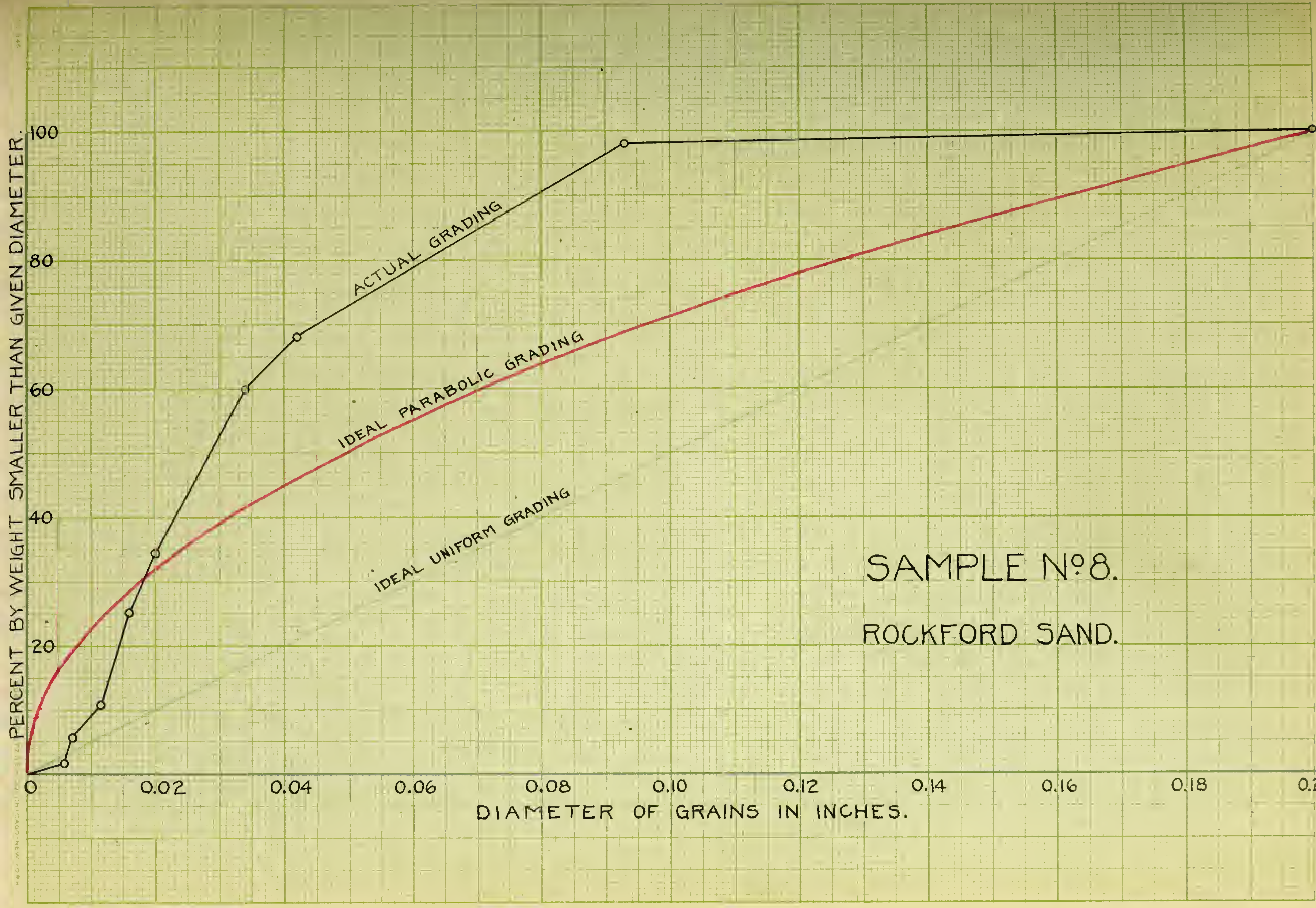

SAMPLE No. 8.
ROCKFORD SAND.
ACTUAL GRADING
IDEAL PARABOLIC GRADING
IDEAL UNIFORM GRADING
PERCENT BY WEIGHT SMALLER THAN GIVEN DIAMETER.
DIAMETER OF GRAINS IN INCHES.
100
80
60
40
20
0
0.02
0.04
0.06
0.08
0.10
0.12
0.14
0.16
0.18
0.20

PLATE 9.

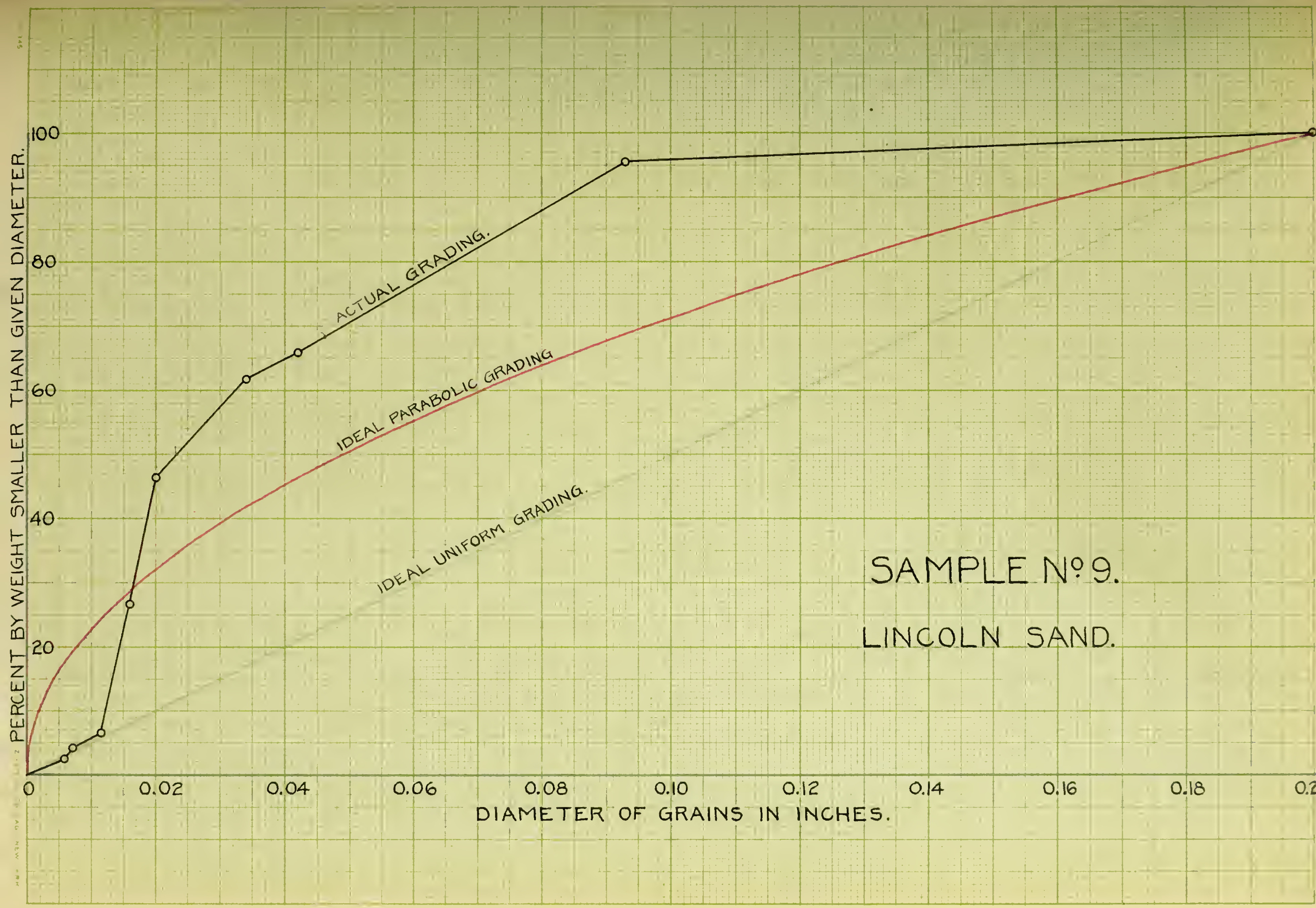
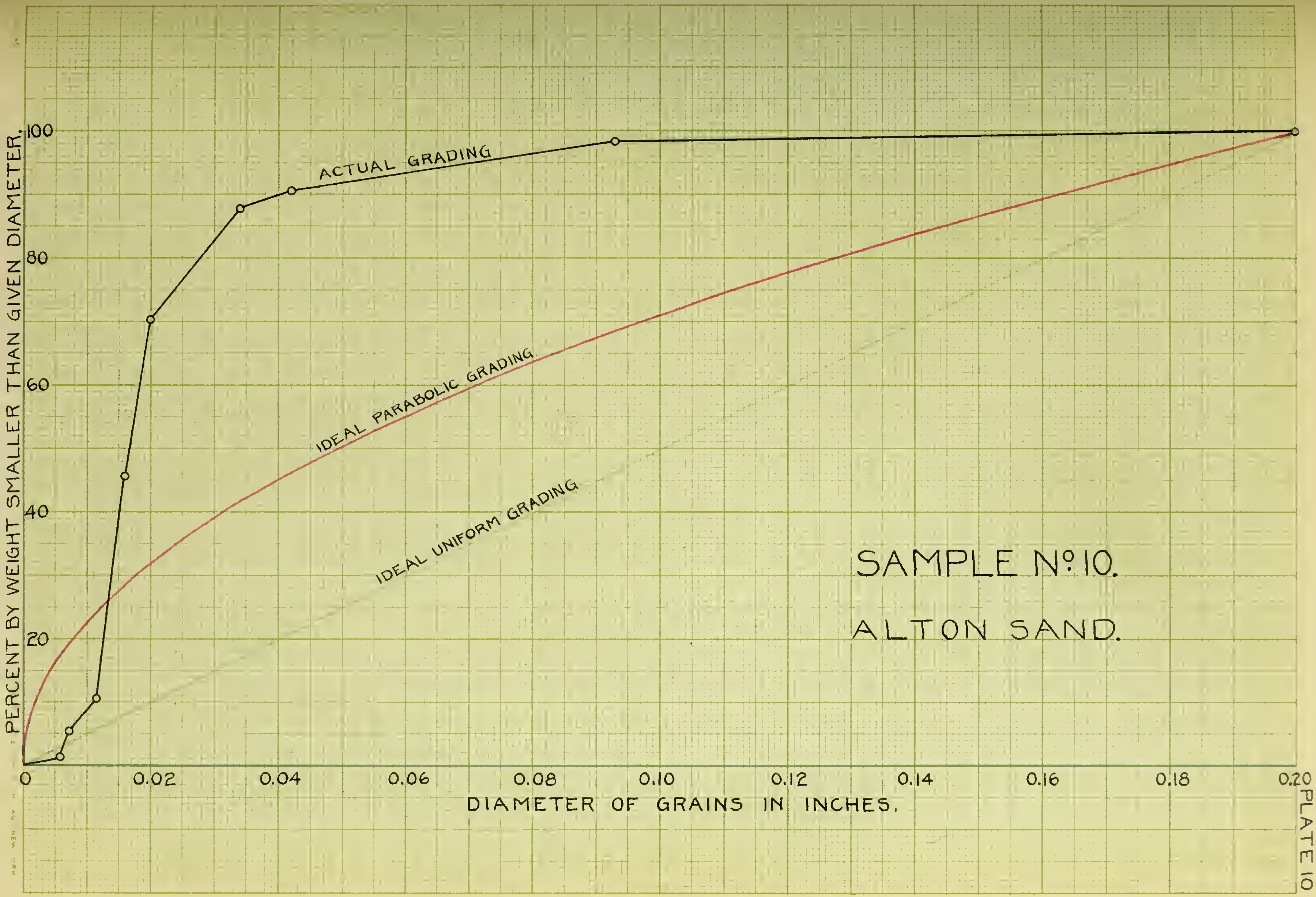
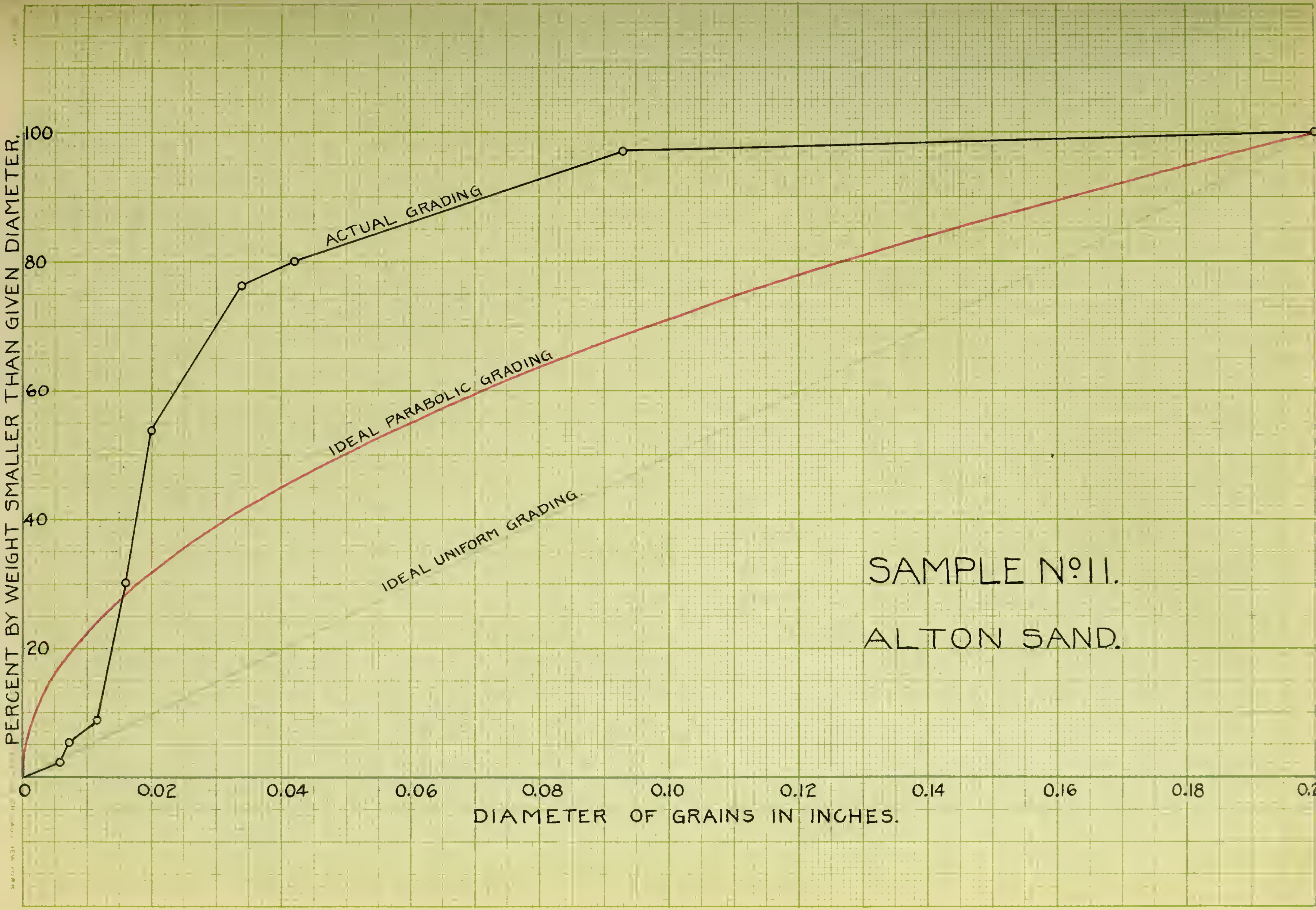

SAMPLE Nº 9.
LINCOLN SAND.
ACTUAL GRADING.
IDEAL PARABOLIC GRADING
IDEAL UNIFORM GRADING.
PERCENT BY WEIGHT SMALLER THAN GIVEN DIAMETER.
DIAMETER OF GRAINS IN INCHES.
0
20
40
60
80
100
0.02
0.04
0.06
0.08
0.10
0.12
0.14
0.16
0.18
0.20

PLATE 10


SAMPLE No. 10.
ALTON SAND.
ACTUAL GRADING
IDEAL PARABOLIC GRADING
IDEAL UNIFORM GRADING
PERCENT BY WEIGHT SMALLER THAN GIVEN DIAMETER.
DIAMETER OF GRAINS IN INCHES.
0
20
40
60
80
100
0.02
0.04
0.06
0.08
0.10
0.12
0.14
0.16
0.18
0.20



SAMPLE Nº 11.
ALTON SAND.
ACTUAL GRADING
IDEAL PARABOLIC GRADING.
IDEAL UNIFORM GRADING.
PERCENT BY WEIGHT SMALLER THAN GIVEN DIAMETER.
DIAMETER OF GRAINS IN INCHES.
0
20
40
60
80
100
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0.12
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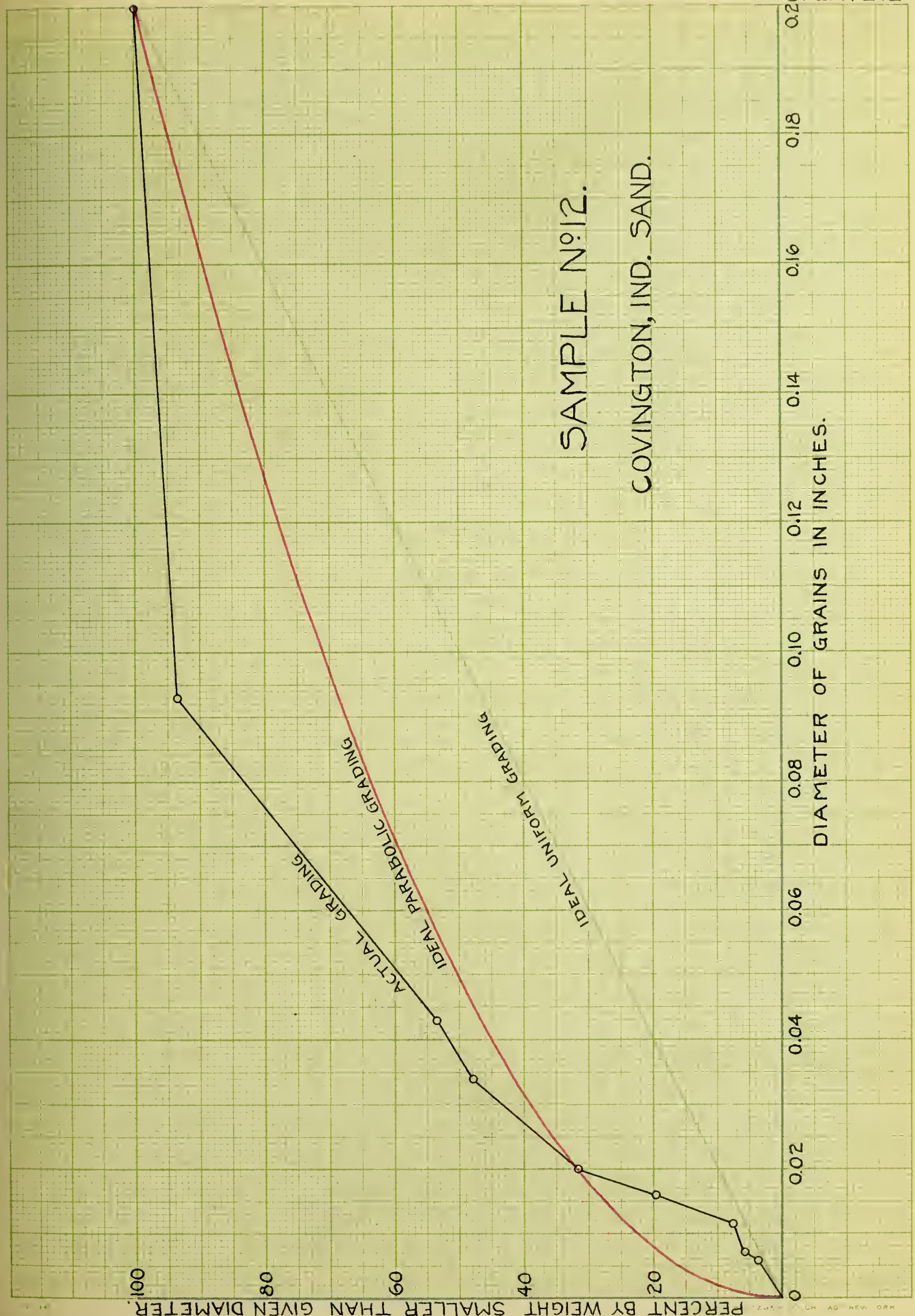
0.16
0.18
0.20

PLATE 12


SAMPLE No. 12.
COVINGTON, IND. SAND.
ACTUAL GRADING
IDEAL PARABOLIC GRADING
IDEAL UNIFORM GRADING
DIAMETER OF GRAINS IN INCHES.
0
0.02
0.04
0.06
0.08
0.10
0.12
0.14
0.16
0.18
0.20
PERCENT BY WEIGHT SMALLER THAN GIVEN DIAMETER.
20
40
60
80
100

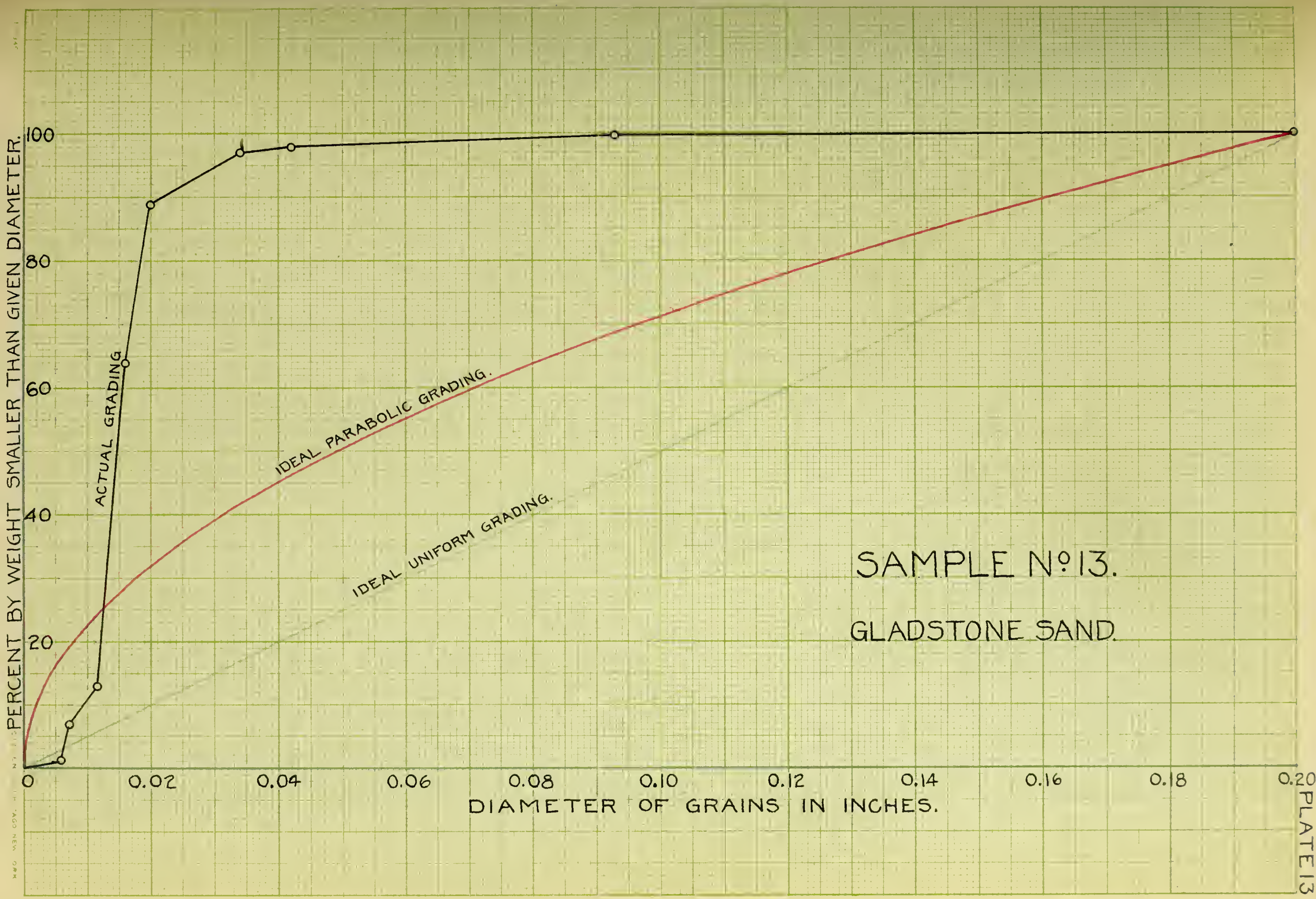
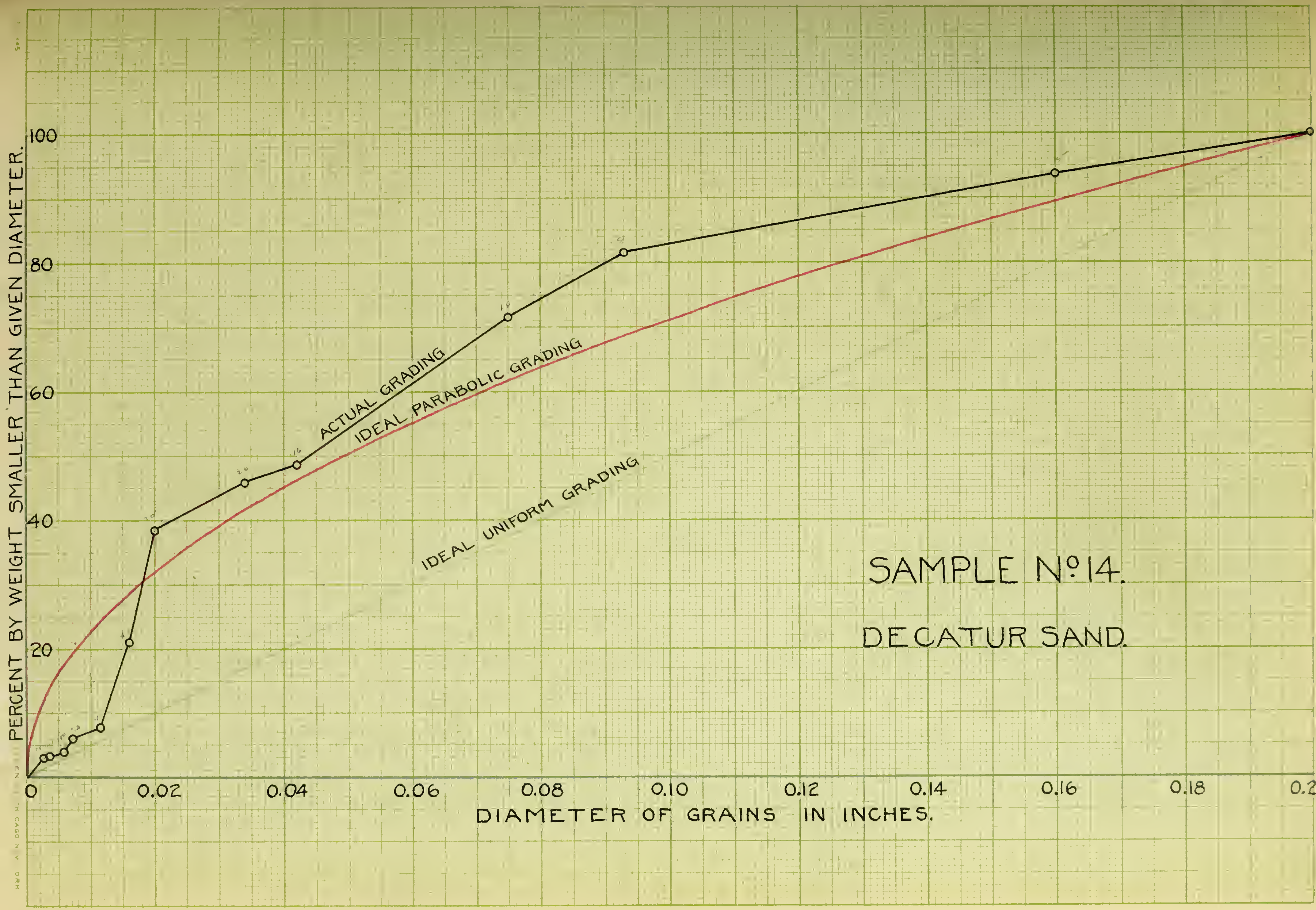

SAMPLE No 13.
GLADSTONE SAND.
ACTUAL GRADING
IDEAL PARABOLIC GRADING.
IDEAL UNIFORM GRADING.
PERCENT BY WEIGHT SMALLER THAN GIVEN DIAMETER.
20
40
60
80
100
DIAMETER OF GRAINS IN INCHES.
0
0.02
0.04
0.06
0.08
0.10
0.12
0.14
0.16
0.18
0.20

PLATE 14.


SAMPLE No. 14.
DECATUR SAND.
ACTUAL GRADING
IDEAL PARABOLIC GRADING
IDEAL UNIFORM GRADING
PERCENT BY WEIGHT SMALLER THAN GIVEN DIAMETER.
DIAMETER OF GRAINS IN INCHES.
100
80
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0.02
0.04
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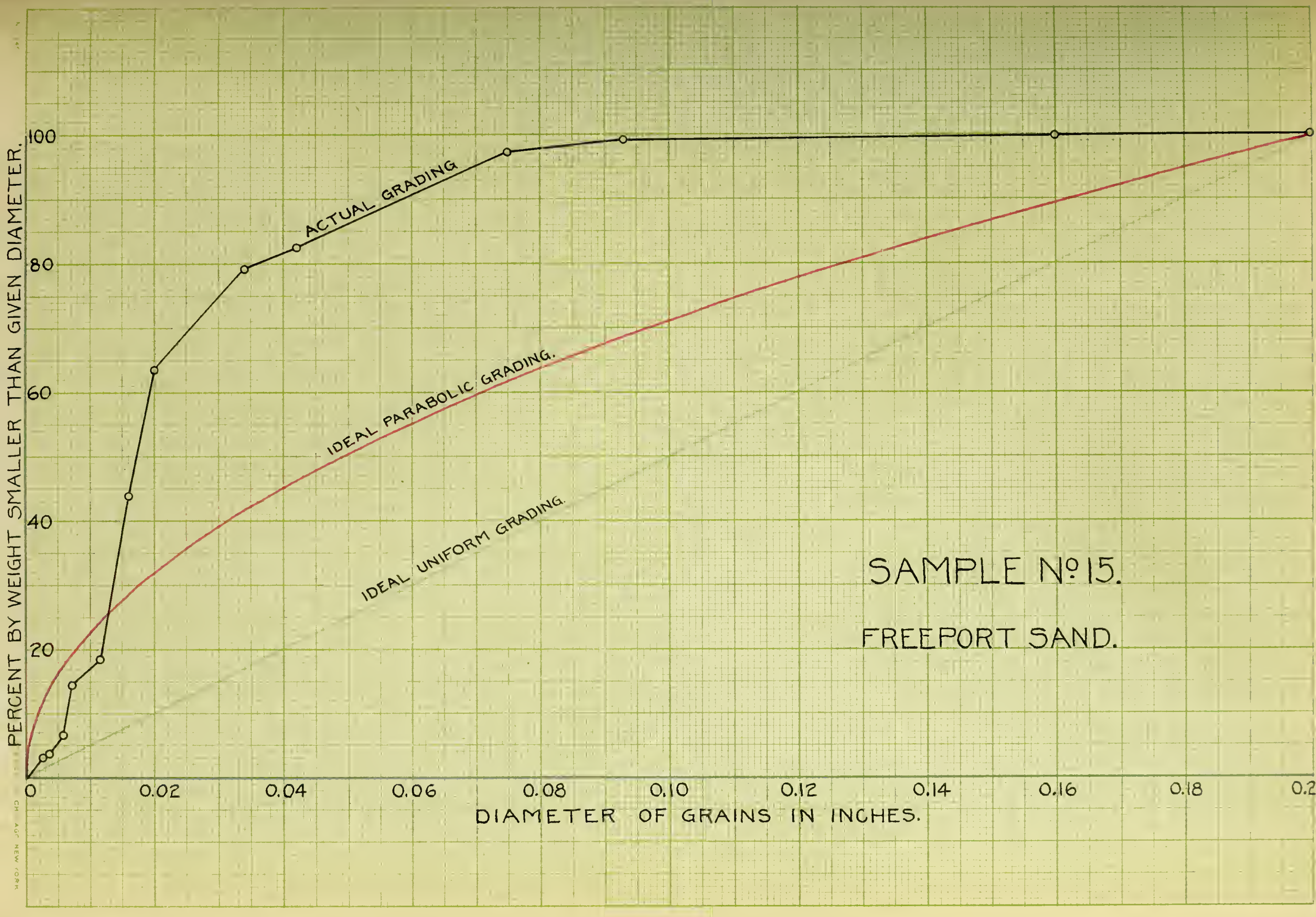
0.08
0.10
0.12
0.14
0.16
0.18
0.20


SAMPLE No. 15.
FREEPORT SAND.
ACTUAL GRADING
IDEAL PARABOLIC GRADING.
IDEAL UNIFORM GRADING.
PERCENT BY WEIGHT SMALLER THAN GIVEN DIAMETER.
100
80
60
40
20
0
0.02
0.04
0.06
0.08
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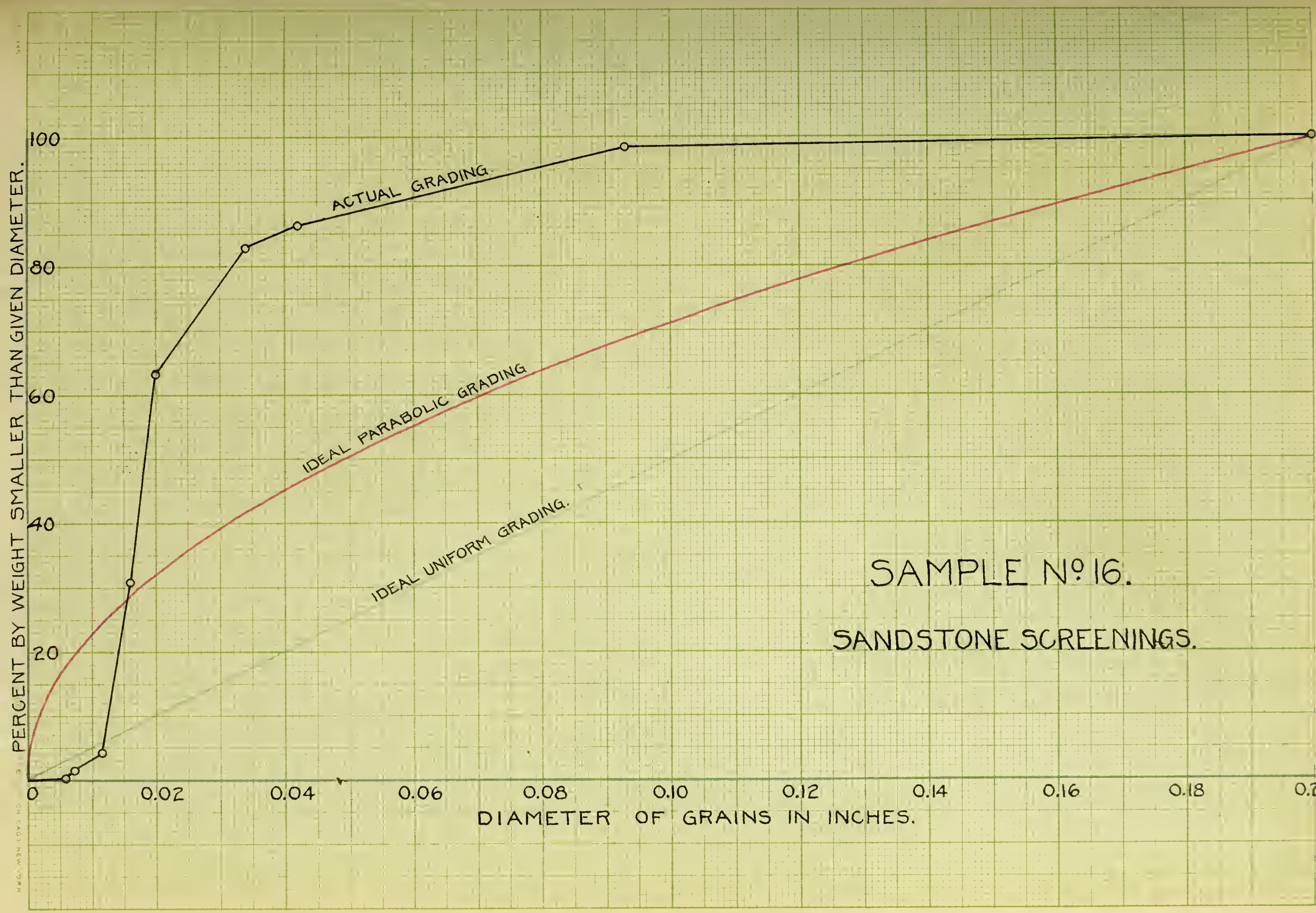
0.12
0.14
0.16
0.18
0.20
DIAMETER OF GRAINS IN INCHES.

PLATE 16.


SAMPLE No. 16.
SANDSTONE SCREENINGS.
ACTUAL GRADING.
IDEAL PARABOLIC GRADING
IDEAL UNIFORM GRADING.
PERCENT BY WEIGHT SMALLER THAN GIVEN DIAMETER.
100
80
60
40
20
0
0.02
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0.08
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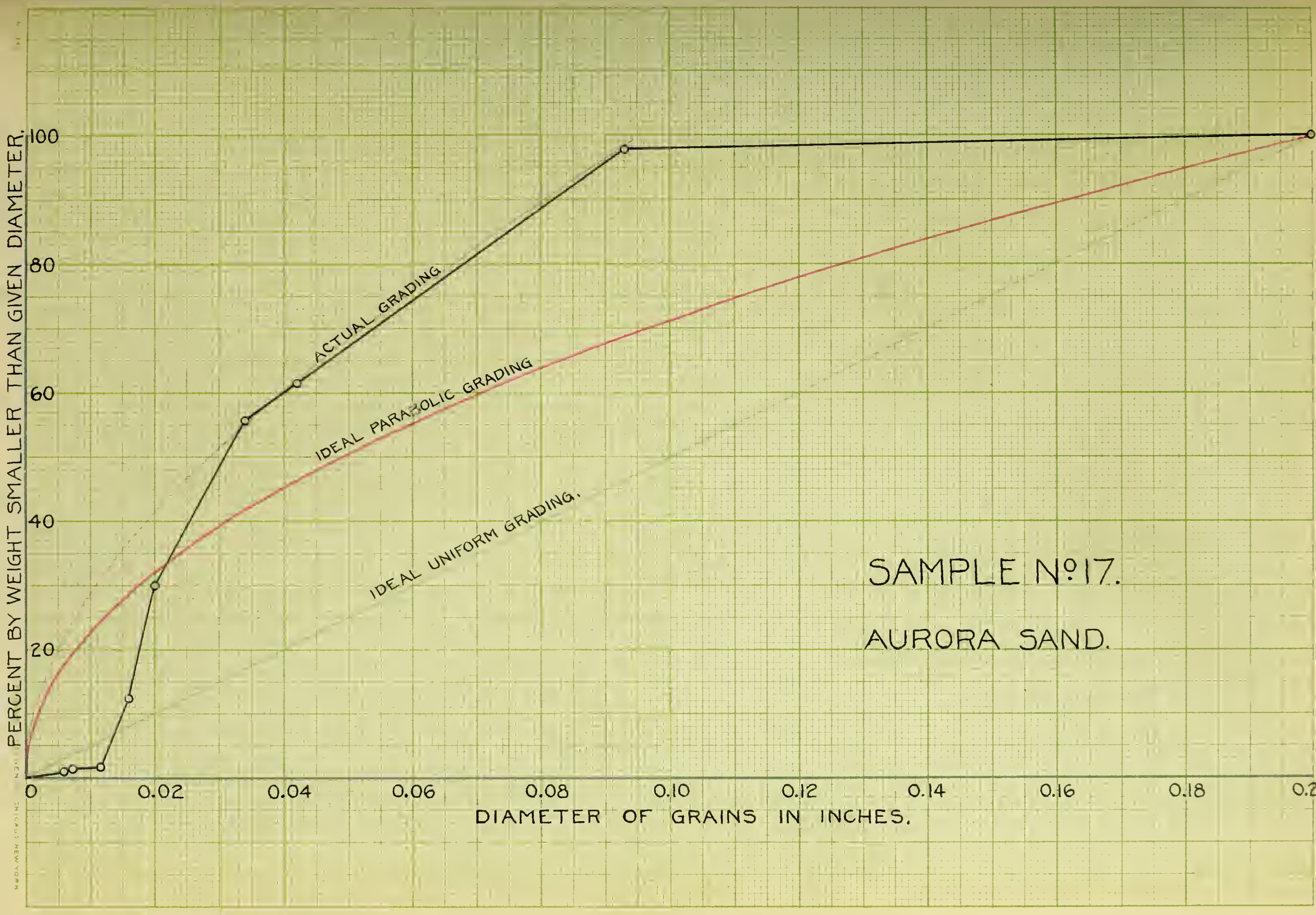
0.12
0.14
0.16
0.18
0.20
DIAMETER OF GRAINS IN INCHES.


100
80
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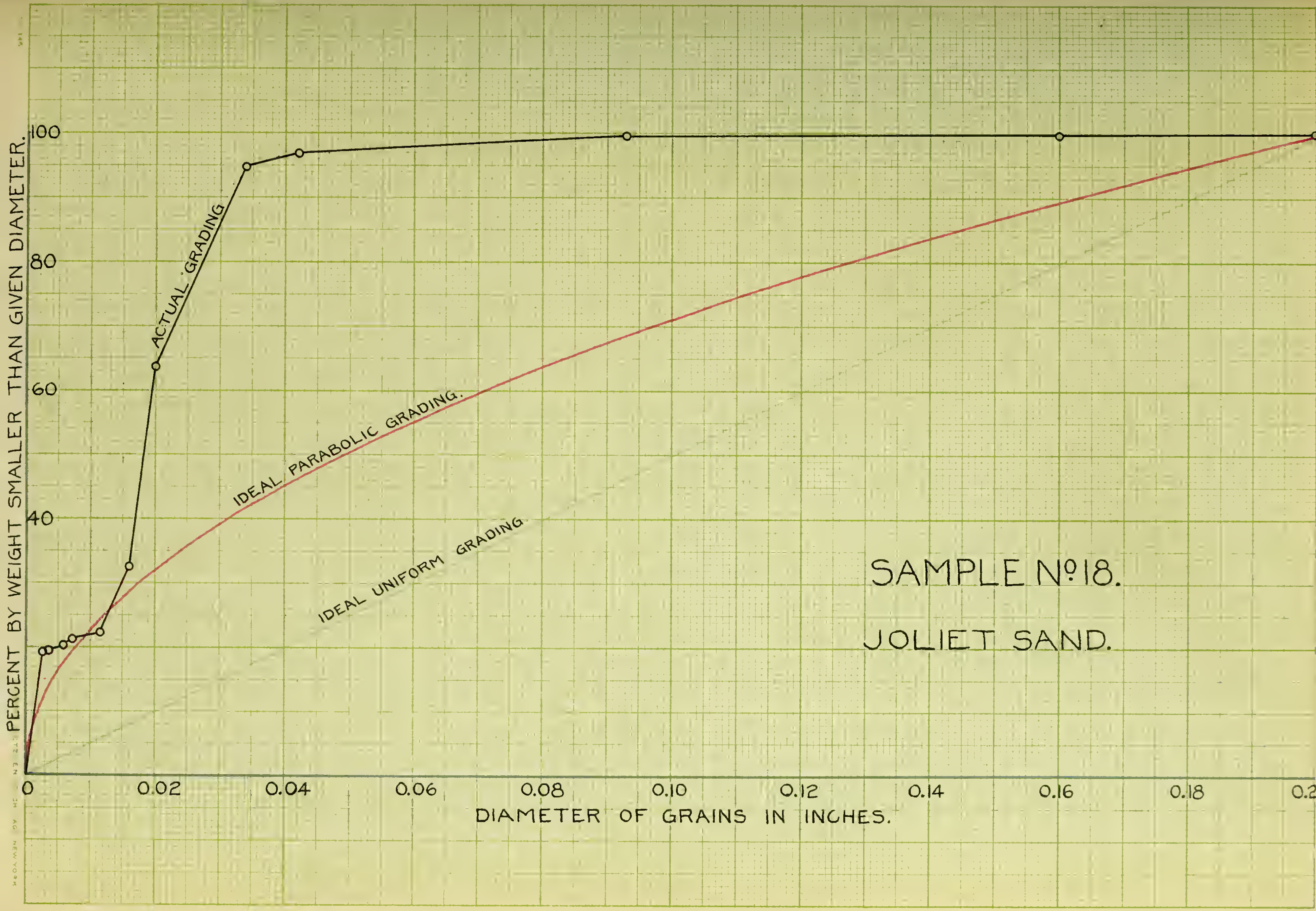
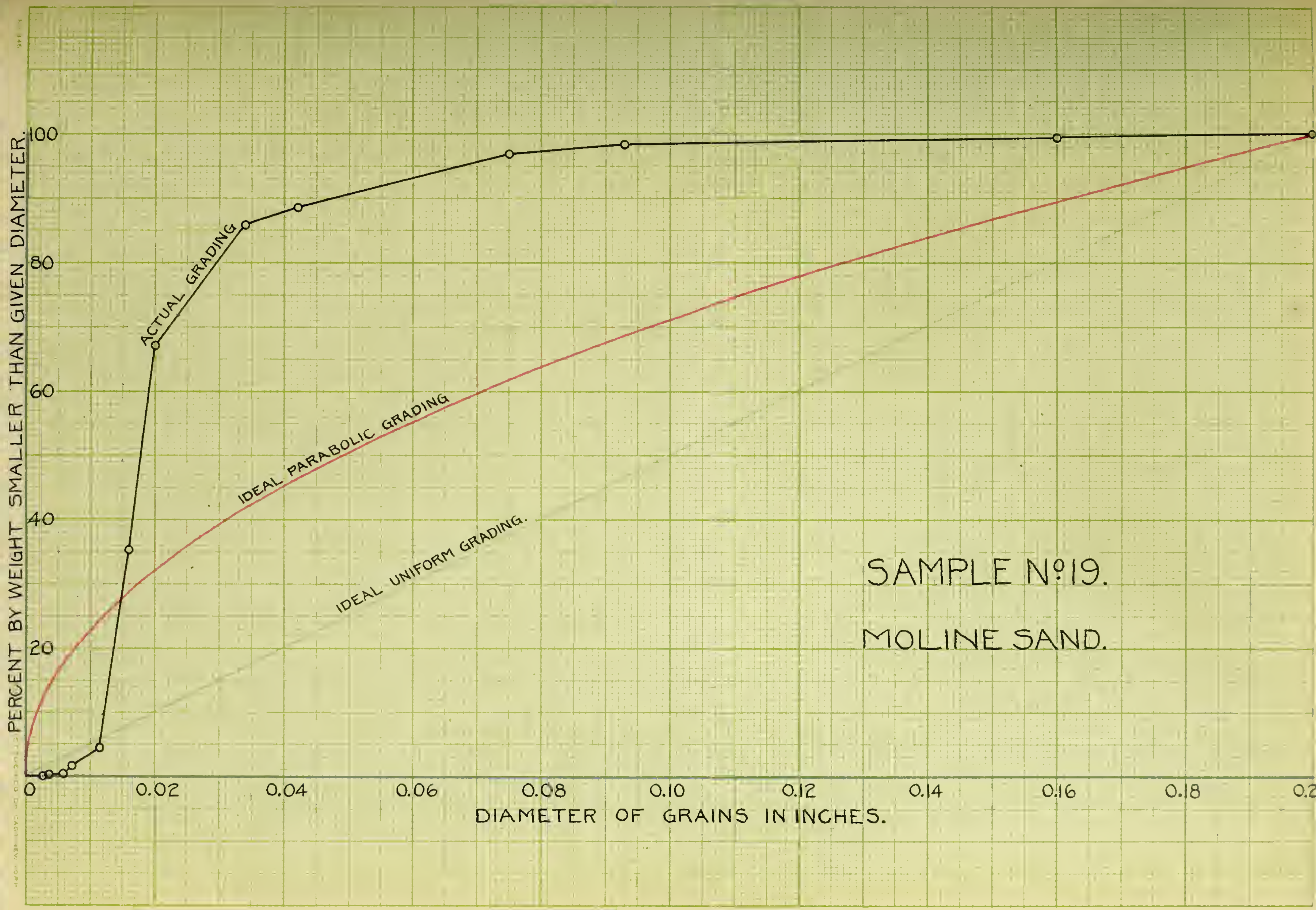
20
0
0.02
0.04
0.06
0.08
0.10
0.12
0.14
0.16
0.18
0.20
PERCENT BY WEIGHT SMALLER THAN GIVEN DIAMETER.
DIAMETER OF GRAINS IN INCHES.
ACTUAL GRADING
IDEAL PARABOLIC GRADING
IDEAL UNIFORM GRADING.
SAMPLE No. 17.
AURORA SAND.

PLATE 18.


SAMPLE No 18.
JOLIET SAND.
ACTUAL GRADING
IDEAL PARABOLIC GRADING.
IDEAL UNIFORM GRADING
PERCENT BY WEIGHT SMALLER THAN GIVEN DIAMETER.
DIAMETER OF GRAINS IN INCHES.
0
0.02
0.04
0.06
0.08
0.10
0.12
0.14
0.16
0.18
0.20
40
60
80
100


SAMPLE Nº 19.
MOLINE SAND.
ACTUAL GRADING
IDEAL PARABOLIC GRADING
IDEAL UNIFORM GRADING.
PERCENT BY WEIGHT SMALLER THAN GIVEN DIAMETER.
DIAMETER OF GRAINS IN INCHES.
0
20
40
60
80
100
0.02
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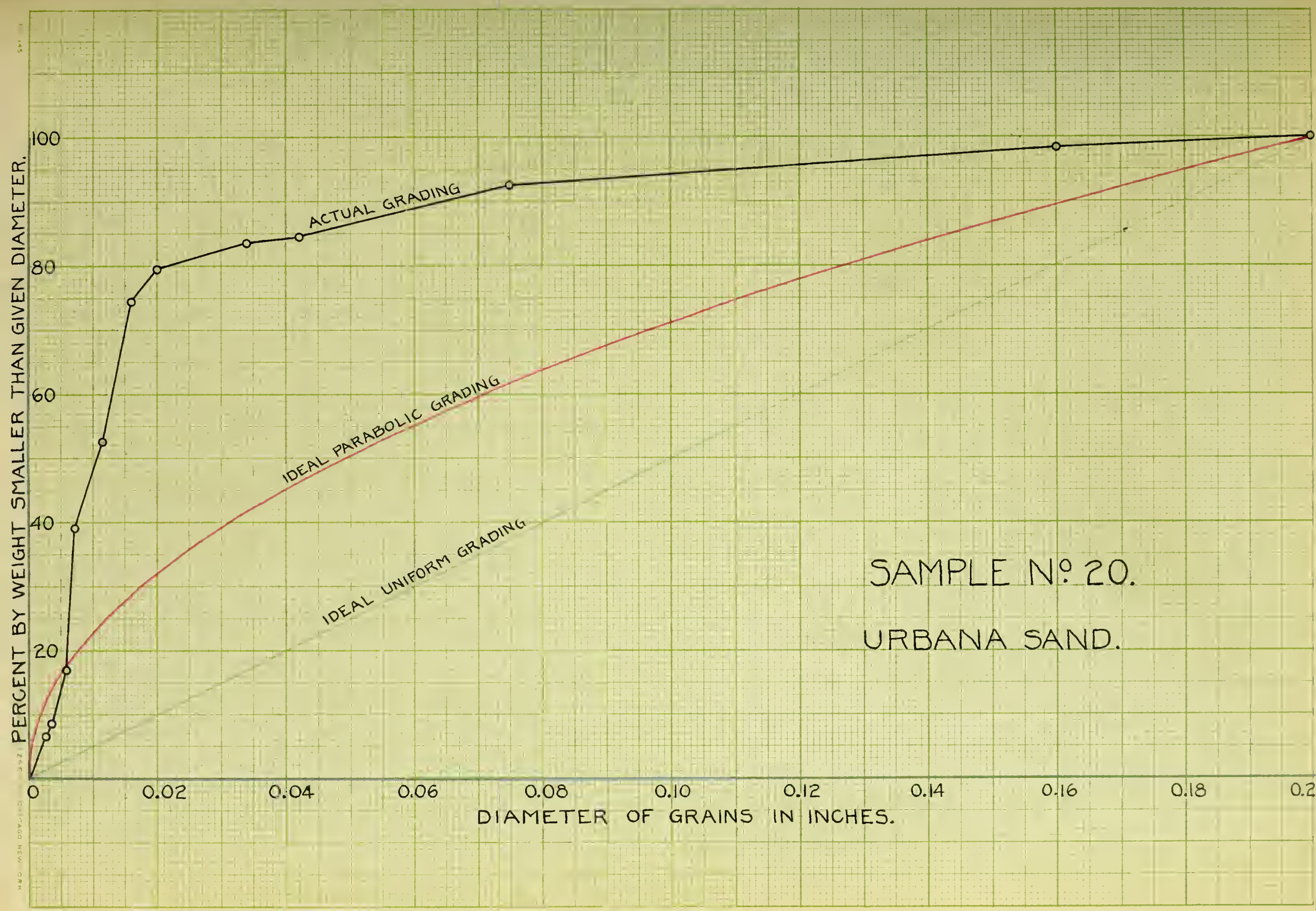
0.18
0.20
PLATE 19.

PLATE 20.



SAMPLE Nº 20.
URBANA SAND.
ACTUAL GRADING
IDEAL PARABOLIC GRADING
IDEAL UNIFORM GRADING
PERCENT BY WEIGHT SMALLER THAN GIVEN DIAMETER.
DIAMETER OF GRAINS IN INCHES.
100
80
60
40
20
0
0.02
0.04
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0.10
0.12
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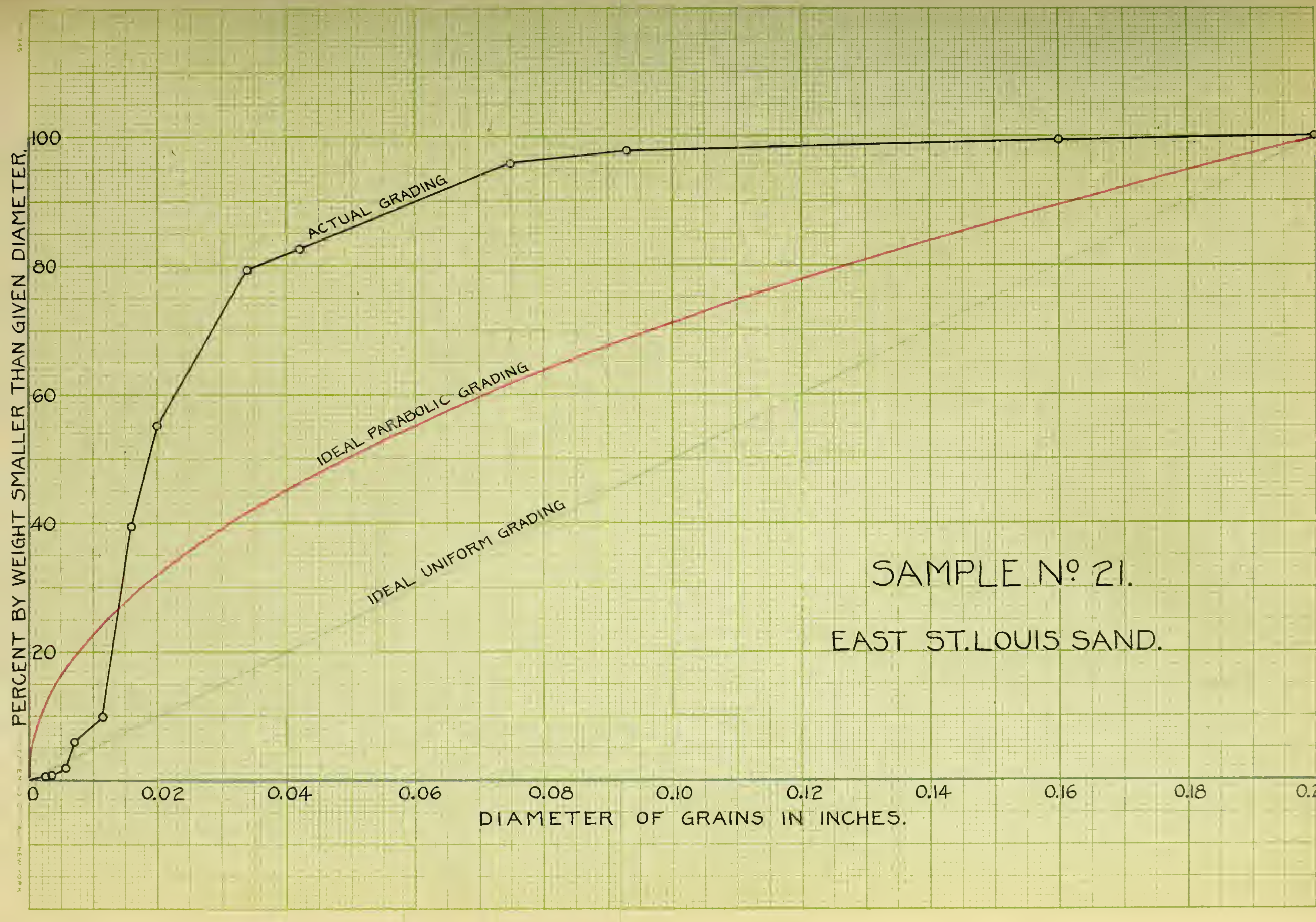
0.18
0.20

PLATE 21.


SAMPLE Nº 21.
EAST ST. LOUIS SAND.
ACTUAL GRADING
IDEAL PARABOLIC GRADING
IDEAL UNIFORM GRADING
PERCENT BY WEIGHT SMALLER THAN GIVEN DIAMETER.
100
80
60
40
20
0
0.02
0.04
0.06
0.08
0.10
0.12
0.14
0.16
0.18
0.20
DIAMETER OF GRAINS IN INCHES.

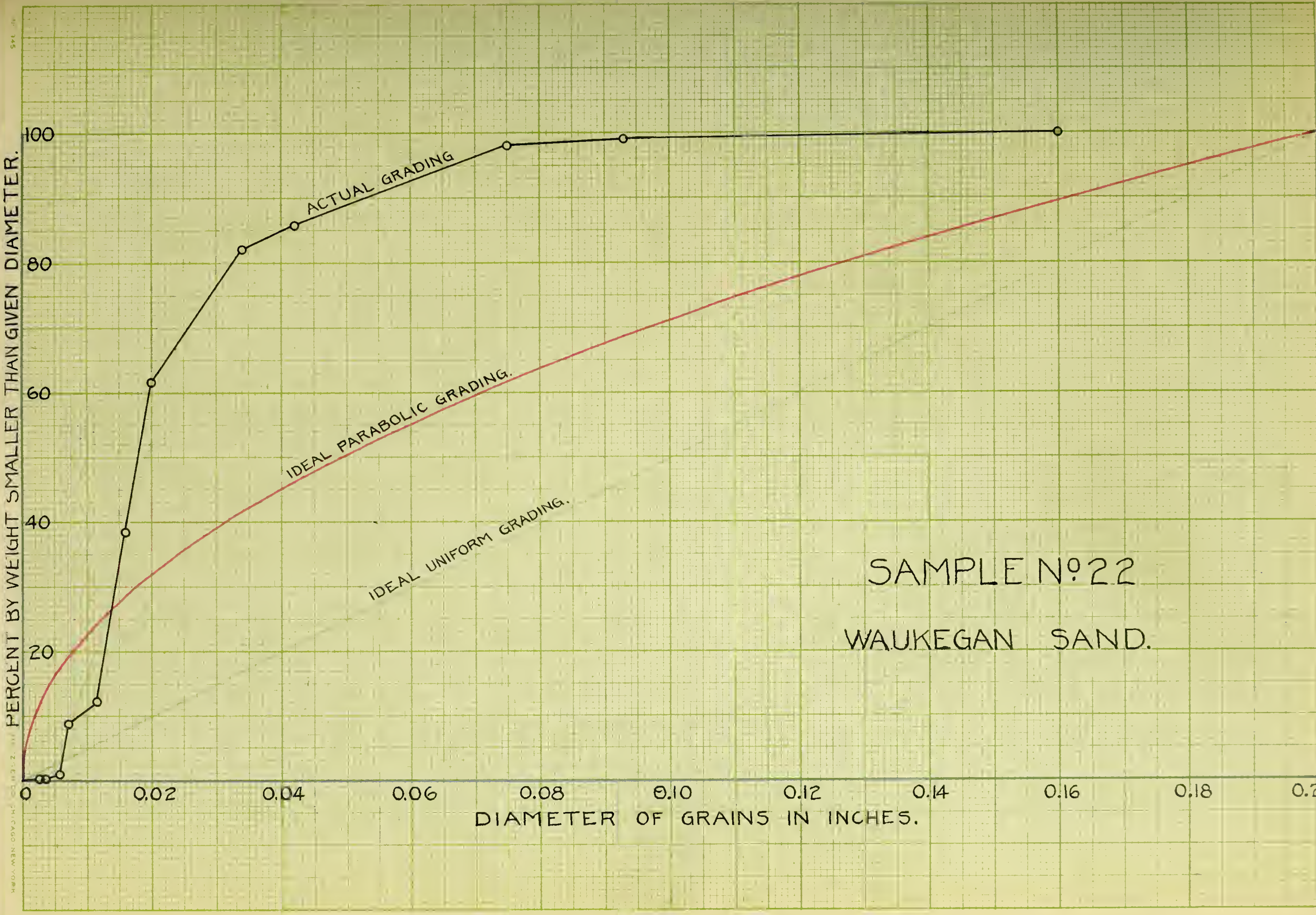

SAMPLE No. 22
WAUKEGAN SAND.
ACTUAL GRADING
IDEAL PARABOLIC GRADING.
IDEAL UNIFORM GRADING.
PERCENT BY WEIGHT SMALLER THAN GIVEN DIAMETER.
DIAMETER OF GRAINS IN INCHES.
0
0.02
0.04
0.06
0.08
0.10
0.12
0.14
0.16
0.18
0.20
20
40
60
80
100

PLATE 23.

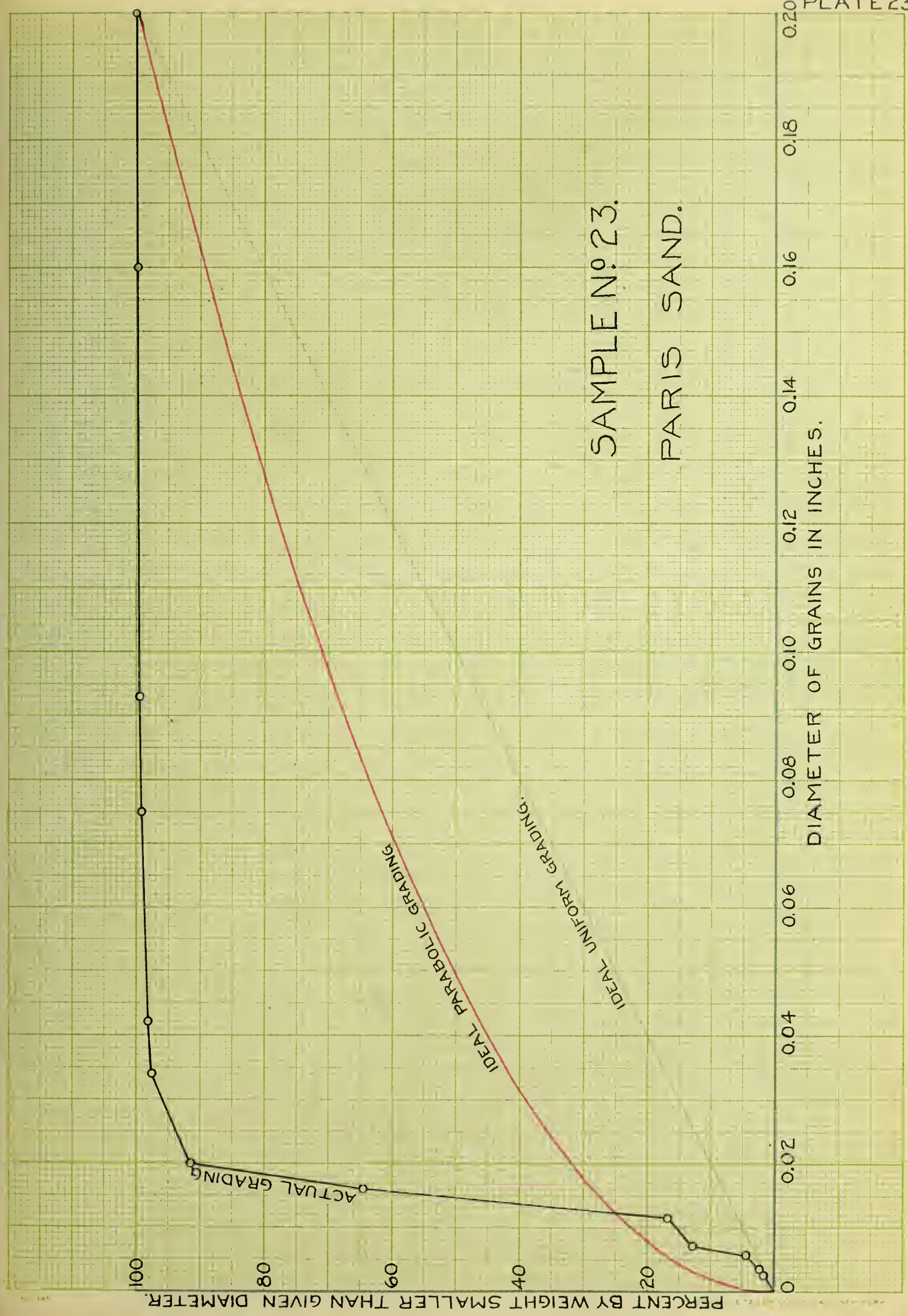
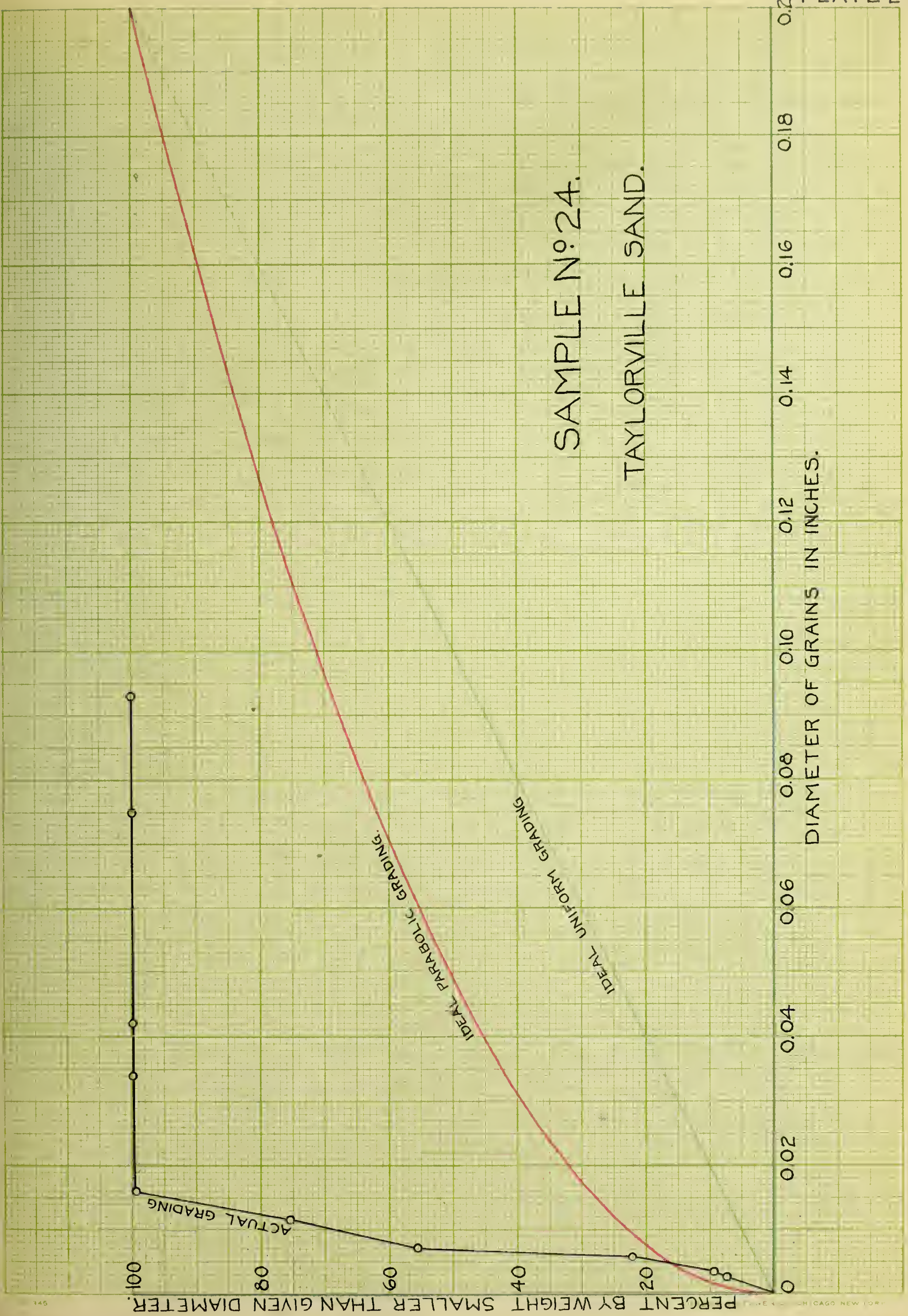
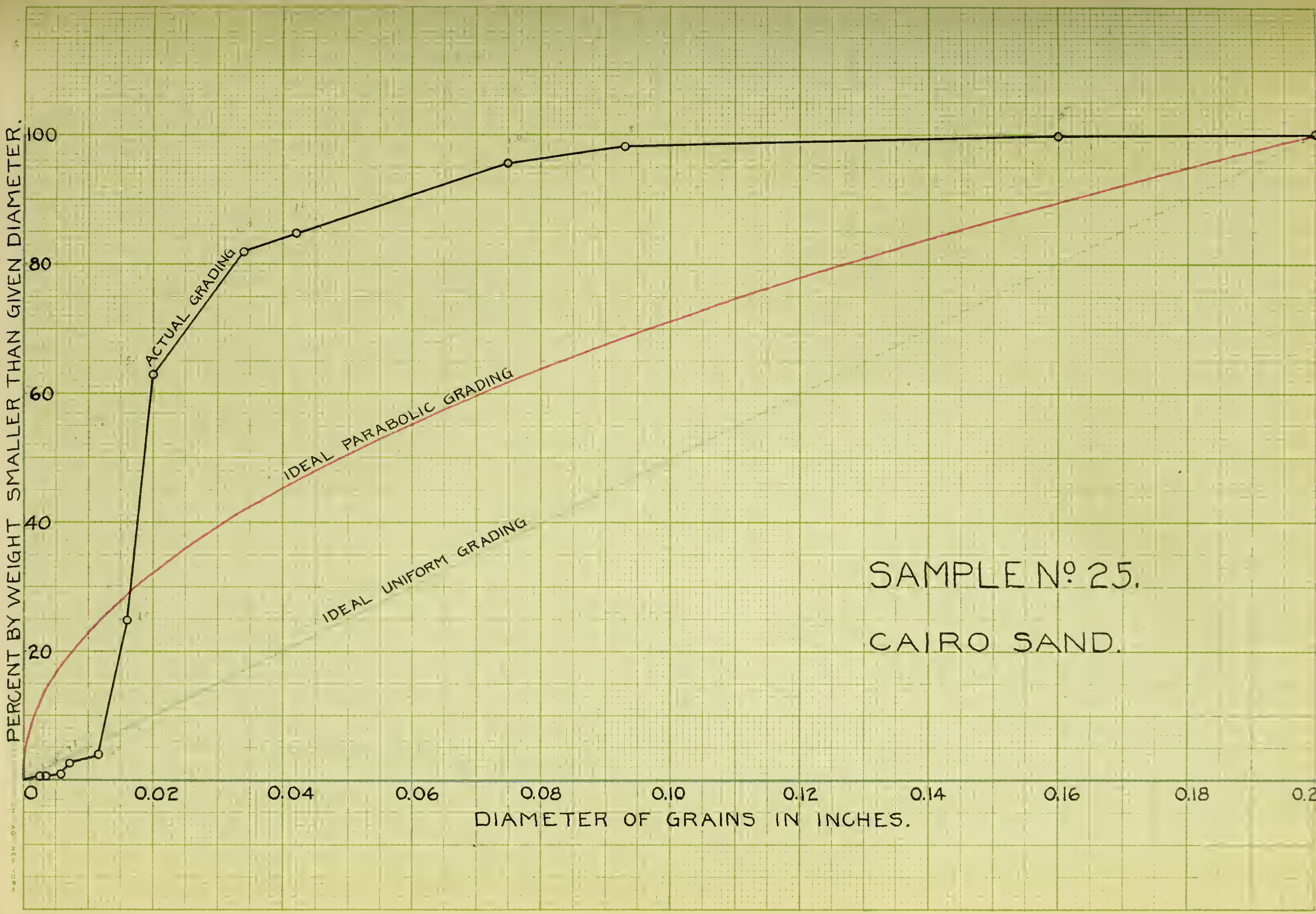

SAMPLE Nº 23.
PARIS SAND.
ACTUAL GRADING
IDEAL PARABOLIC GRADING
IDEAL UNIFORM GRADING.
DIAMETER OF GRAINS IN INCHES.
PERCENT BY WEIGHT SMALLER THAN GIVEN DIAMETER.
0
0.02
0.04
0.06
0.08
0.10
0.12
0.14
0.16
0.18
0.20
20
40
60
80
100

PLATE 24.



SAMPLE No. 24.
TAYLORVILLE SAND.
ACTUAL GRADING
IDEAL PARABOLIC GRADING.
IDEAL UNIFORM GRADING
DIAMETER OF GRAINS IN INCHES.
0
0.02
0.04
0.06
0.08
0.10
0.12
0.14
0.16
0.18
0.20
PERCENT BY WEIGHT SMALLER THAN GIVEN DIAMETER.
20
40
60
80
100

PLATE 25.



SAMPLE Nº 25.
CAIRO SAND.
ACTUAL GRADING
IDEAL PARABOLIC GRADING
IDEAL UNIFORM GRADING
PERCENT BY WEIGHT SMALLER THAN GIVEN DIAMETER.
DIAMETER OF GRAINS IN INCHES.
100
80
60
40
20
0
0.02
0.04
0.06
0.08
0.10
0.12
0.14
0.16
0.18
0.20

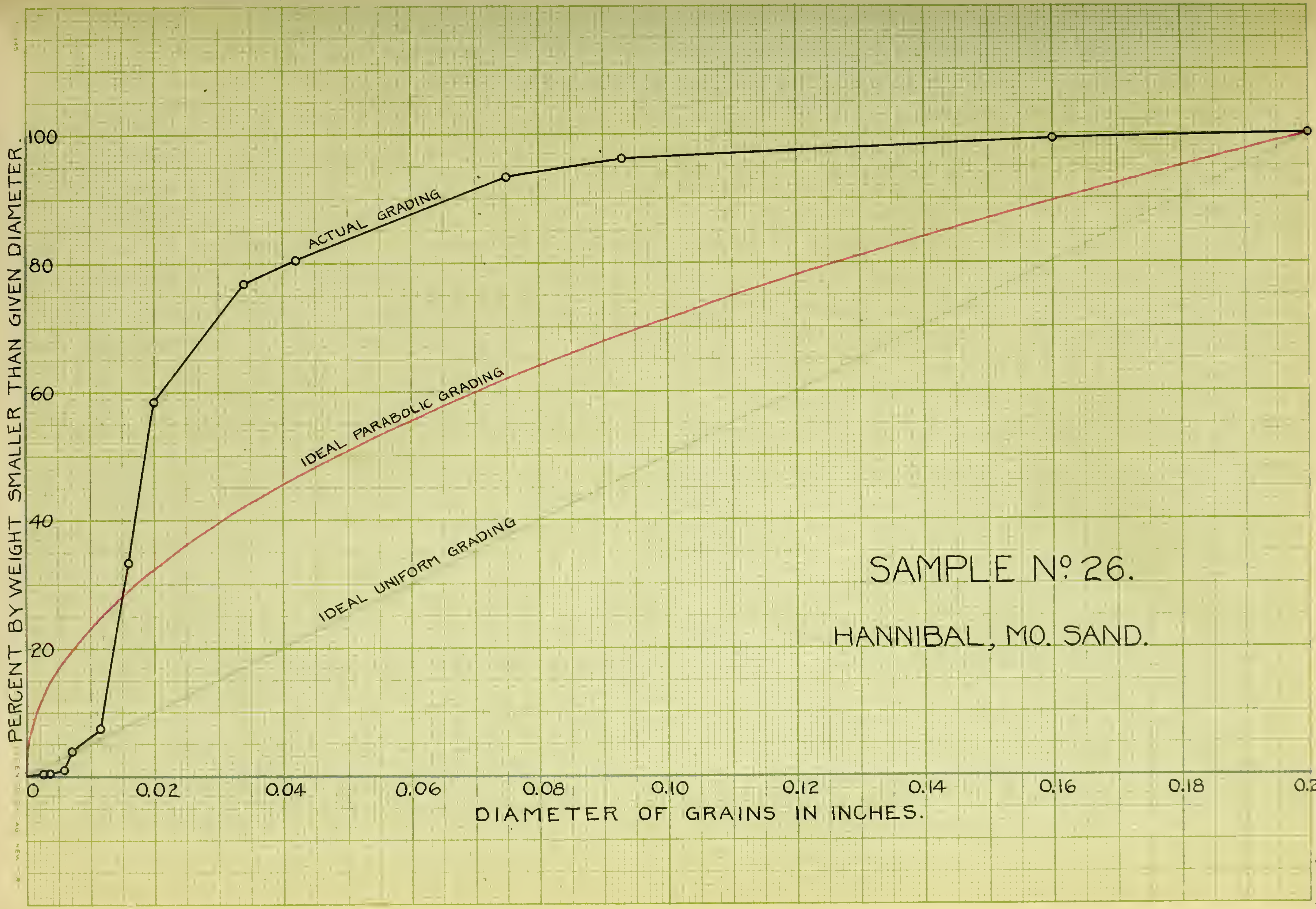

SAMPLE Nº 26.
HANNIBAL, MO. SAND.
ACTUAL GRADING
IDEAL PARABOLIC GRADING
IDEAL UNIFORM GRADING
PERCENT BY WEIGHT SMALLER THAN GIVEN DIAMETER.
DIAMETER OF GRAINS IN INCHES.
100
80
60
40
20
0
0.02
0.04
0.06
0.08
0.10
0.12
0.14
0.16
0.18
0.20

PLATE 27.

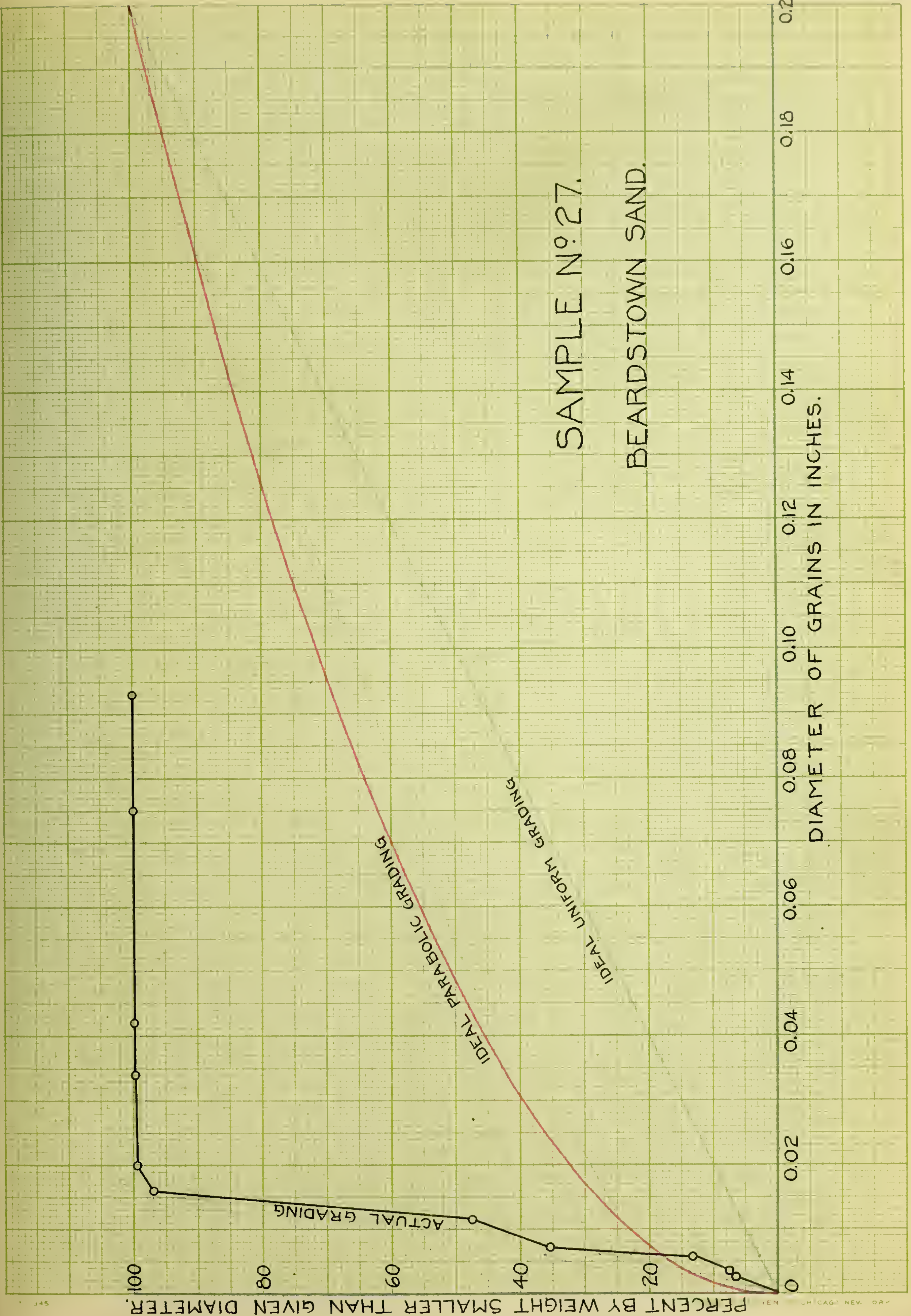

SAMPLE No. 27.
BEARDSTOWN SAND.
ACTUAL GRADING
IDEAL PARABOLIC GRADING
IDEAL UNIFORM GRADING
0
0.02
0.04
0.06
0.08
0.10
0.12
0.14
0.16
0.18
0.20
DIAMETER OF GRAINS IN INCHES.
20
40
60
80
100
PERCENT BY WEIGHT SMALLER THAN GIVEN DIAMETER.

PLATE 28.

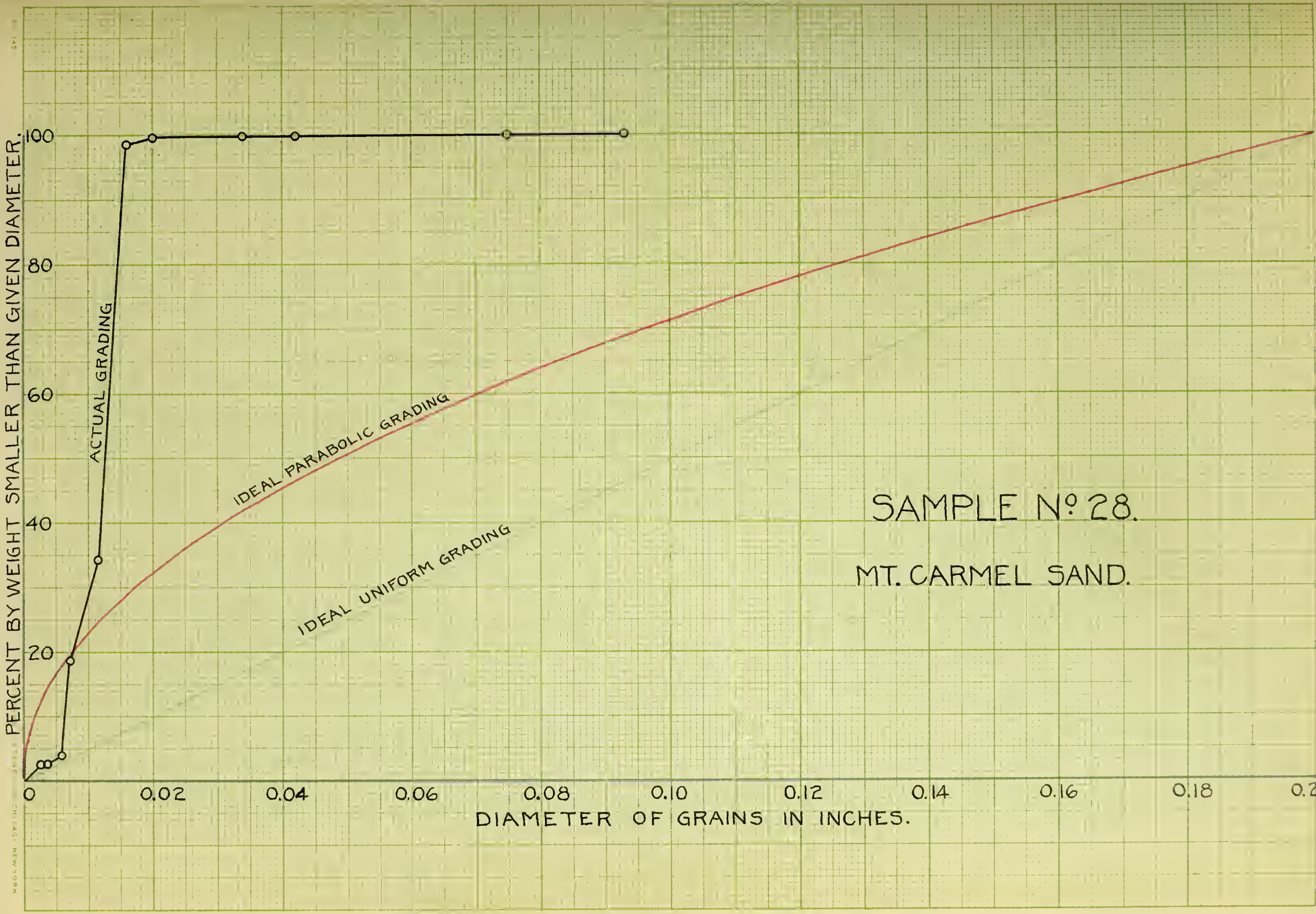
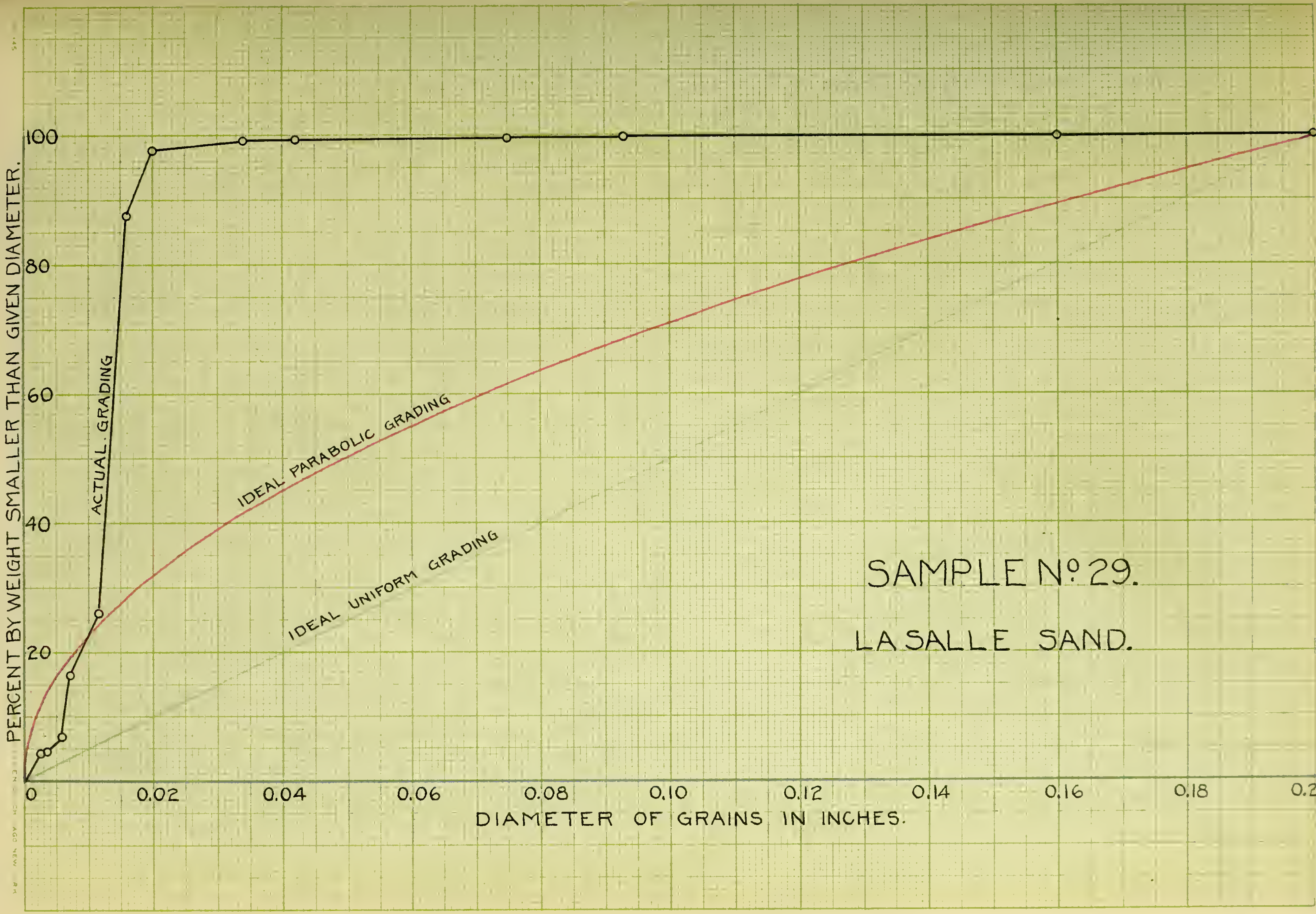

SAMPLE No. 28.
MT. CARMEL SAND.
ACTUAL GRADING
IDEAL PARABOLIC GRADING
IDEAL UNIFORM GRADING
PERCENT BY WEIGHT SMALLER THAN GIVEN DIAMETER.
DIAMETER OF GRAINS IN INCHES.
0
20
40
60
80
100
0.02
0.04
0.06
0.08
0.10
0.12
0.14
0.16
0.18
0.20

PLATE 29.


SAMPLE Nº 29.
LA SALLE SAND.
ACTUAL. GRADING
IDEAL PARABOLIC GRADING
IDEAL UNIFORM GRADING
PERCENT BY WEIGHT SMALLER THAN GIVEN DIAMETER.
DIAMETER OF GRAINS IN INCHES.
0
20
40
60
80
100
0.02
0.04
0.06
0.08
0.10
0.12
0.14
0.16
0.18
0.20

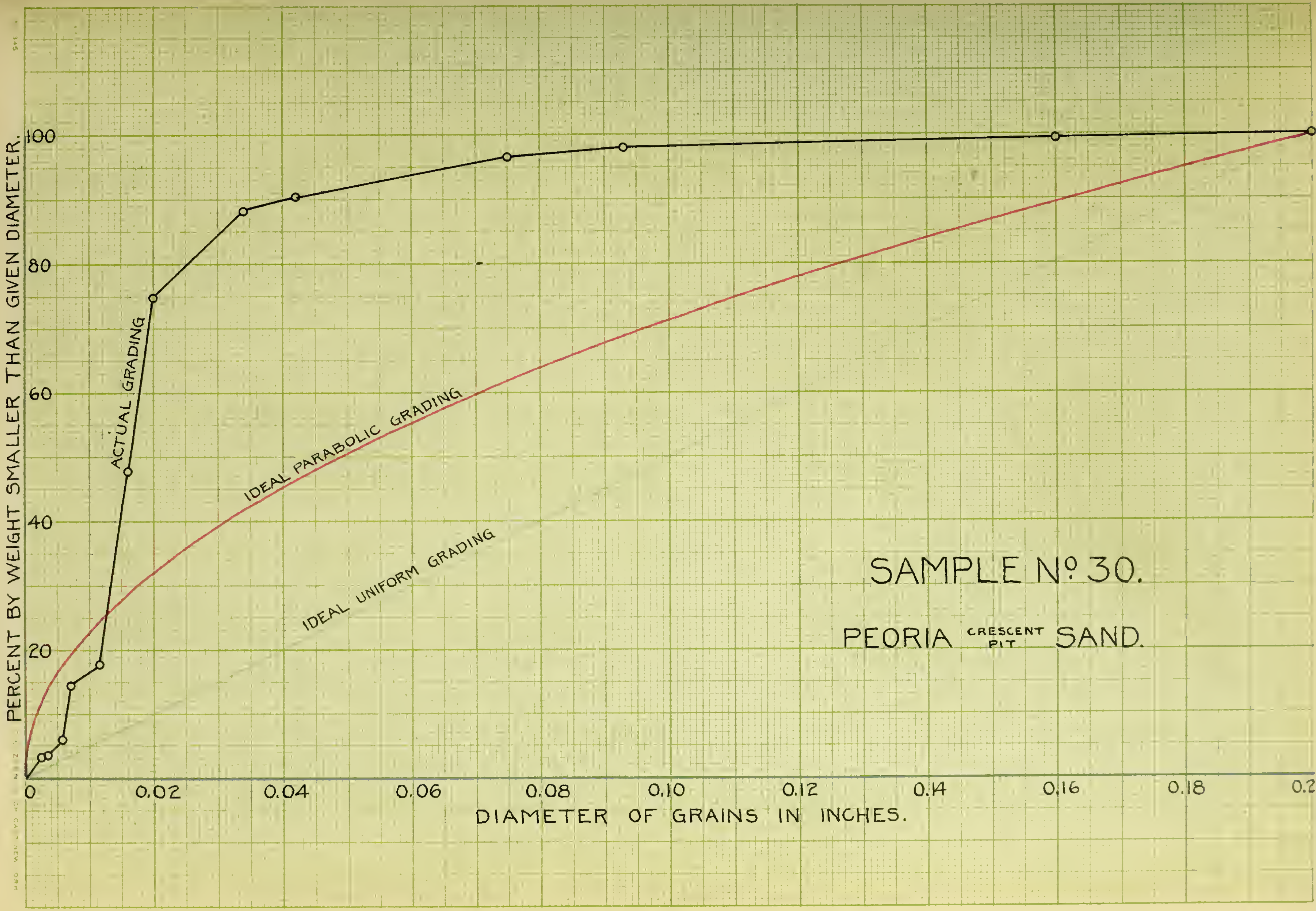

SAMPLE Nº 30.
PEORIA CRESCENT PIT SAND.
ACTUAL GRADING
IDEAL PARABOLIC GRADING
IDEAL UNIFORM GRADING
PERCENT BY WEIGHT SMALLER THAN GIVEN DIAMETER.
100
80
60
40
20
0
0.02
0.04
0.06
0.08
0.10
0.12
0.14
0.16
0.18
0.20
DIAMETER OF GRAINS IN INCHES.

PLATE 31.

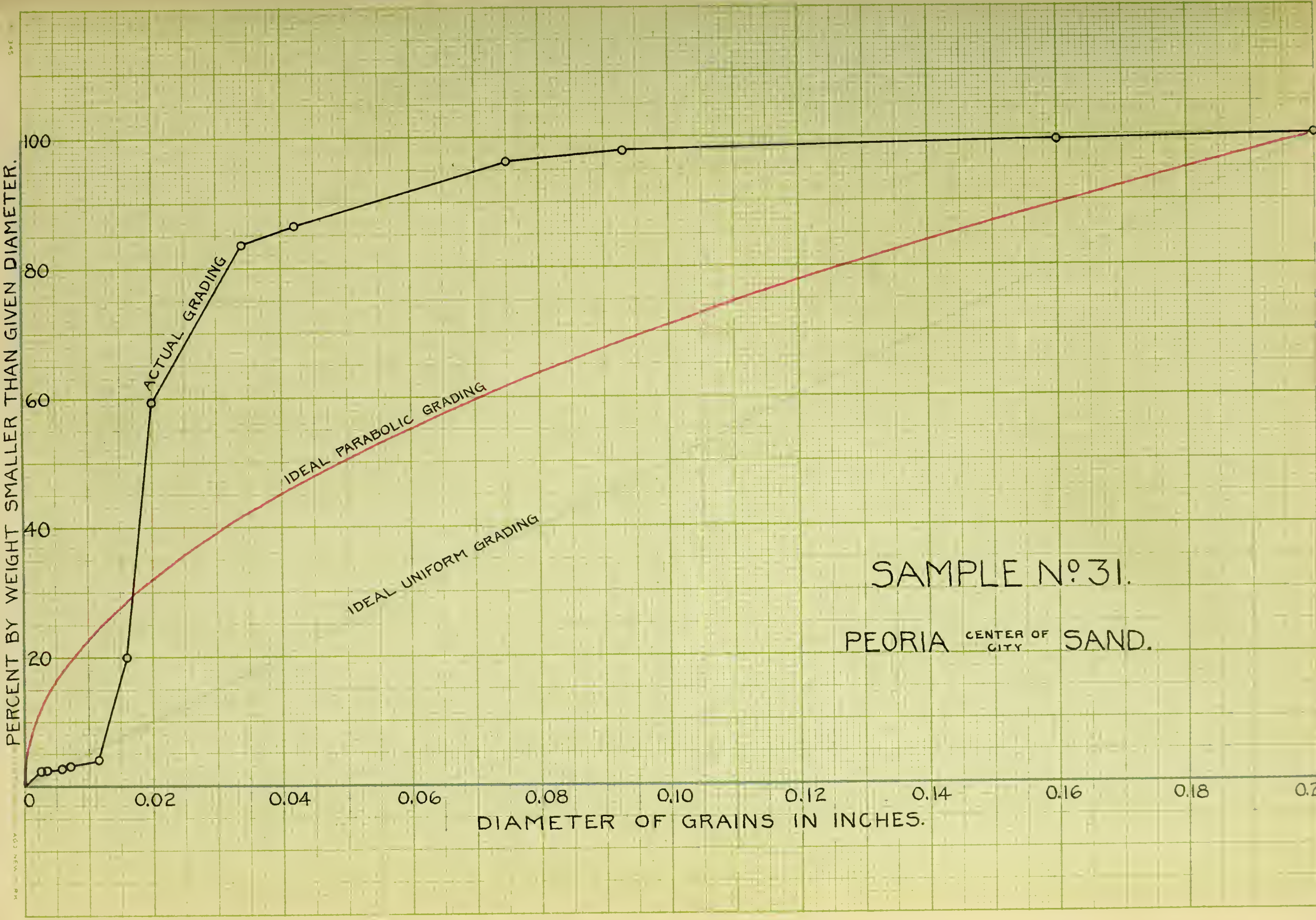

SAMPLE Nº 31.
PEORIA CENTER OF CITY SAND.
ACTUAL GRADING
IDEAL PARABOLIC GRADING
IDEAL UNIFORM GRADING
PERCENT BY WEIGHT SMALLER THAN GIVEN DIAMETER.
DIAMETER OF GRAINS IN INCHES.
0
20
40
60
80
100
0.02
0.04
0.06
0.08
0.10
0.12
0.14
0.16
0.18
0.20

PLATE 32.

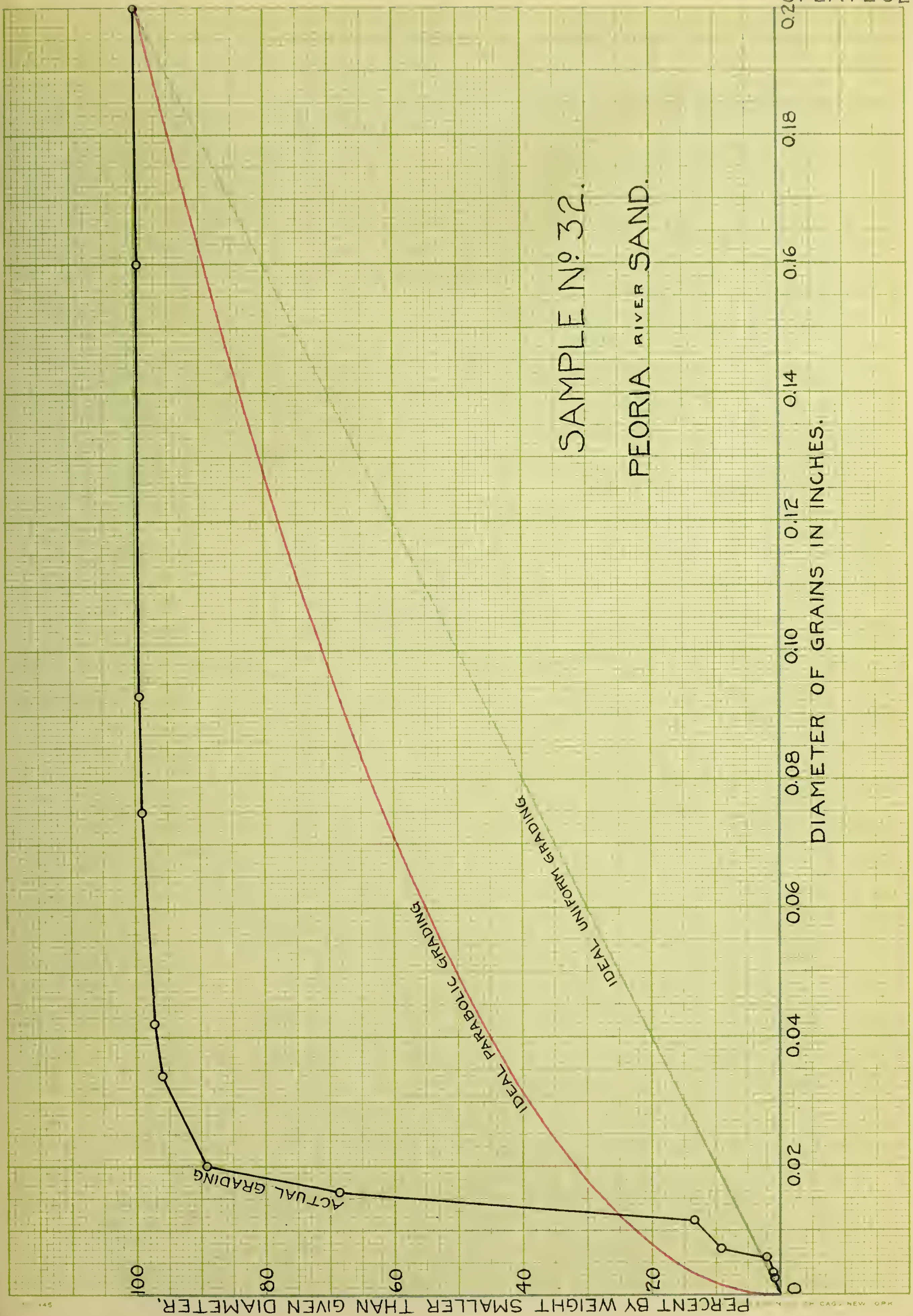
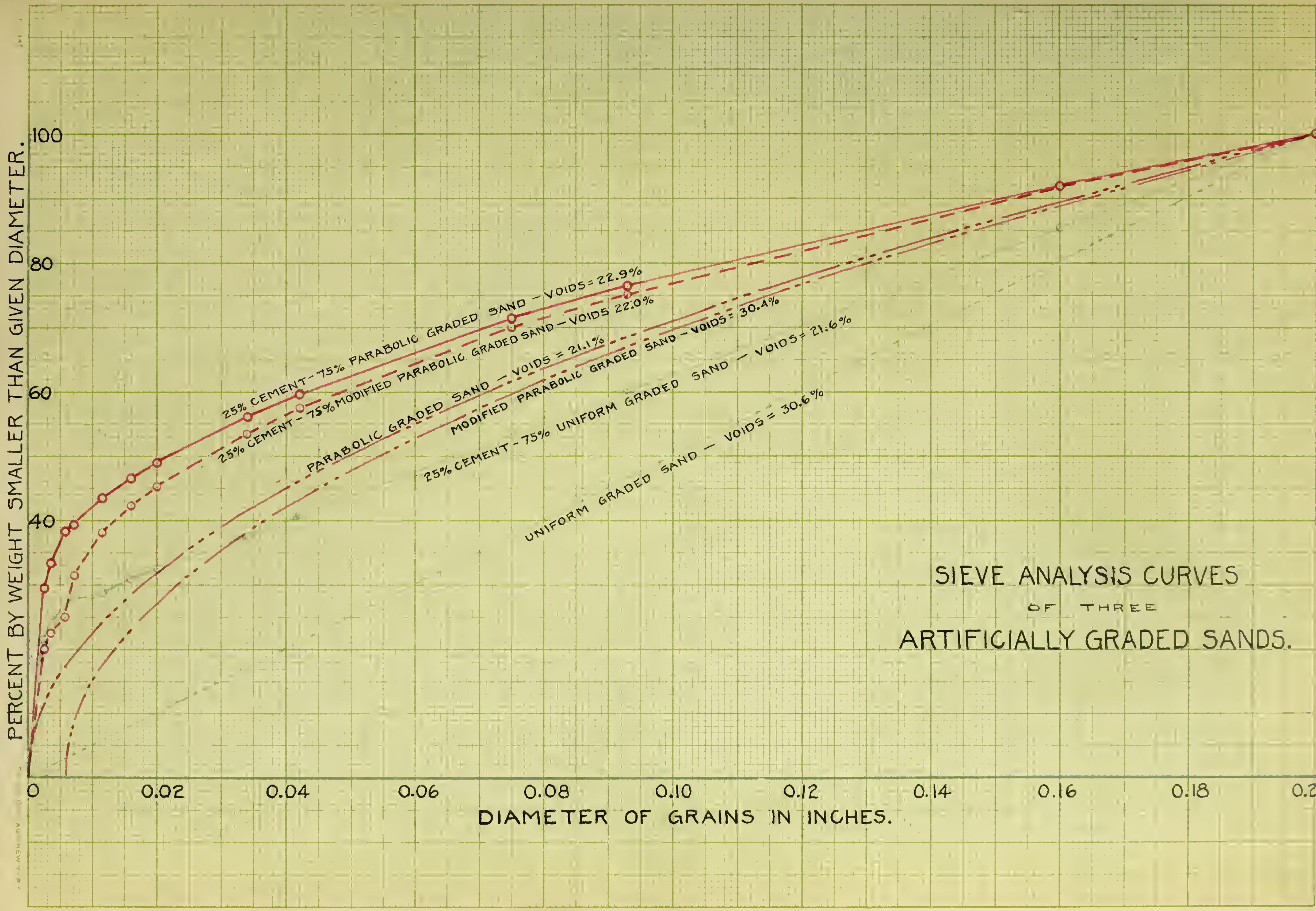

SAMPLE No. 32.
PEORIA RIVER SAND.
ACTUAL GRADING
IDEAL PARABOLIC GRADING
IDEAL UNIFORM GRADING
DIAMETER OF GRAINS IN INCHES.
PERCENT BY WEIGHT SMALLER THAN GIVEN DIAMETER.
0
0.02
0.04
0.06
0.08
0.10
0.12
0.14
0.16
0.18
0.20
20
40
60
80
100

PLATE 33.


SIEVE ANALYSIS CURVES
OF THREE
ARTIFICIALLY GRADED SANDS.
PERCENT BY WEIGHT SMALLER THAN GIVEN DIAMETER.
DIAMETER OF GRAINS IN INCHES.
100
80
60
40
0
0.02
0.04
0.06
0.08
0.10
0.12
0.14
0.16
0.18
0.20
25% CEMENT - 75% PARABOLIC GRADED SAND - VOIDS = 22.9%
25% CEMENT - 75% MODIFIED PARABOLIC GRADED SAND - VOIDS 22.0%
PARABOLIC GRADED SAND - VOIDS = 21.1%
MODIFIED PARABOLIC GRADED SAND - VOIDS = 30.4%
25% CEMENT - 75% UNIFORM GRADED SAND - VOIDS = 21.6%
UNIFORM GRADED SAND - VOIDS = 30.6%